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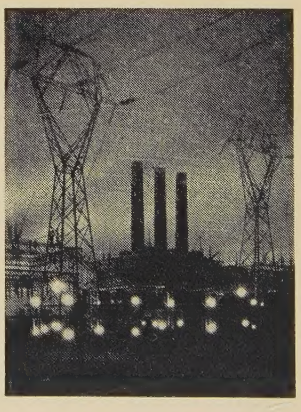
The Cover

Ashtabula, Ohio, plant of the Cleveland Electric Illuminating Company, at twilight



High Lights

Induction-Motor Constants. The constants of single-phase induction motors usually are computed by means of polyphase formulas, with special adaptations to single-phase motor construction. A method of calculating electrical constants has been developed specifically for the single-phase capacitor motor, but is equally applicable to other types of single-phase motors (*pages 333–8*).

Flux Locus. A concept for the locus of rotor flux in a single-phase induction motor has been suggested in which the flux is referred to axes fixed with respect to the rotor; this concept is said to be less involved than either the cross-field or revolving-field theories although it does not lend itself to quantitative mathematical treatment (*pages 331–2*).

Inductance of Solenoids. A paper in this issue presents the derivation of series expansion formulas for calculating the mutual inductance of solenoids. The new formulas are derived from basic formulas of the National Bureau of Standards, and replace some of the older absolute formulas that require exacting numerical computations (*pages 347–53*).

Train Heating. Weather conditions have marked effects on the electrical energy requirements for traction and heating of trains, cold weather causing considerable increase in operating expense when power is purchased. A study of the relations of energy and temperature is reported in this issue (*pages 361–2*).

Rectifier Circuit. Measurement of transient oscillations of small angular swing in synchronous machines, when made by the method employing a pilot alternator connected to the main machine, may be simplified by a circuit employing rectifier tubes that enables the oscillograph to plot the actual displacement curve directly (*pages 339–40*).

Copper-Oxide Rectifiers. An equivalent circuit has been developed for representing copper-oxide rectifiers by replacing the rectifier element with 2 constant resistances effective during the 2 directions of current flow. Circuits are analyzed and the computed results obtained by this method are compared with oscillograms (*pages 354–60*).

Carbon Arcs. Low-intensity, high-intensity, and flame arcs, 3 distinct types of carbon arcs, have individual characteristics, and each is affected differently by variations in arc conditions. Effective application requires consideration of these characteristics, and adaptation of operating conditions to them (*pages 319–24*).

Railway-Motor Standards. Advancements in railway motor design, and the development of new types of equipment for which no standards have existed, have made necessary a revision of the AIEE standards in this field; the new standards have been adopted as "American Tentative Standards" (*pages 312–13*).

Lightning Protection. Some 75 per cent of all interruptions on overhead electric power transmission circuits are attributed to lightning. To reduce these interruptions and thus improve service, several methods of protecting power lines against lightning have been developed (*pages 314–18*).

Committee Meetings. During the Institute's 1937 winter convention, meetings of many Institute committees and subcommittees were held (*pages 380–2*). Four technical conferences also were held at the convention under auspices of Institute committees (*pages 383–4*).

Nominations for Institute Officers. In accordance with the AIEE by-laws, the national nominating committee met during the recent winter convention. At that meeting, nominees for Institute offices for the year 1937–38, were designated (*page 375*).

Report on Dues. The final report of the special committee appointed several years ago to consider dues and related matters was presented to the Institute's board of directors at its meeting held during the recent winter convention; the committee recommended no change in dues (*pages 388–9*).

Vehicle Lighting. Railroad cars, trolley cars, and motor coaches are now being equipped with decorative and highly effective lighting installations that greatly improve reading conditions for passengers; illumination levels are from 10 to 20 footcandles at the reading plane (*pages 302–04*).

Core Loss. The magnitude of intersheet eddy-current loss in laminated cores, which may be important in large cores and with high clamping pressure, has been investigated, and a more rigorous formula for eddy currents in rectangular sections has been derived (*pages 344–6*).

Current Loci. The variation of currents and voltages in a general linear a-c network connected to a single adjustable branch in which the current is adjusted under some given restriction is considered in a paper in this issue; the various loci are shown (*pages 325–30*).

Circular Loci. The method of circular loci may be conveniently applied in the calculation of the variation of currents and voltages when self impedances are changed in various types of circuits operated at constant frequency. This method has been applied to the delta-star connection (*pages 341–3*).

Lamme Medal Awarded. The Institute's Lamme Medal for 1936 has been awarded to Frank Conrad of the Westinghouse company, for "his pioneering and basic developments in the fields of electric metering and protective systems" (*page 388*).

Edison Medal Presented. The 1936 Edison Medal, highest award of the AIEE, was presented to Alex Dow, president, Detroit Edison Company, at a special session of the Institute's recent winter convention (*pages 378–80*).

Institute Members Honored. Five Institute members were honored recently by Eta Kappa Nu, honorary electrical engineering society, in connection with the naming of America's outstanding young electrical engineer for 1936 (*pages* 389–90).

Capacitance. Calculation of the capacitance of a parallel-plate air capacitor may be made exact by a method that takes into account the fringing of the flux; several approximate formulas are also useful (*pages 363–6*).

Power and People. Social relations of technical advances, considered from the aspect of the arts of energy production and distribution, are discussed in an address delivered upon the occasion of the presentation of the Edison Medal for 1936 (*pages 305–11*).

Winter Convention. Reports of the various activities at the Institute's 1937 winter convention held during the last week in January are given in this issue (*pages 371–87*).

Directors Meet. For the first time, the AIEE board of directors met on 2 successive afternoons during the 1937 winter convention; many matters of importance to the Institute were acted upon (*pages 374–5*).

North Eastern District Meeting. Plans for the Institute's North Eastern District meeting to be held in Buffalo, N. Y., May 5–7, 1937, are progressing (*page 390*).

Discussions. Some of the papers presented at the AIEE South West District meeting at Dallas, Texas, in October 1936 are discussed in this issue (*pages 367–70*).

DISCUSSIONS

Appearing in this issue are discussions of the following papers:

Electrical Engineering

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Speaking of Conventions —

A Message From the President

A N almost universal characteristic of the human family is the desire "to come together"—"*con venio*"—"conene." Twice in the last month have I en this demonstrated: once in New York : the winter convention of the AIEE; and gain in a far different way at Colon, Panna, where the picturesque natives of the thmus dropped every regular occupation iat they might fittingly celebrate the anual carnival just prior to the beginning of ent. I am told that the term "carnival" derived from 2 Latin words, *vale* (farewell) id *carnus* (meat). In gay, picturesque, id sometimes ludicrous costumes, by arades through colorfully decorated streets, id enlivened by bands, the throng bade a erry farewell to meat.

With the convention closing January 29, id an Institute trip through the South cheduled to begin at Miami, Fla., on Febiary 12, Mrs. MacCutcheon and I feel that rovidence must have arranged that the rench liner "Lafayette" should sail at 11 .m. on the 29th, and touch at Havana on ie morning of the 12th. The Pan Amerian Airways ship at 3 p.m. should have devered us at Miami in ample time for the lorida Section meeting in the evening, but storm prevented this. On the trip the iip touched at Martinique, Trinidad, renada, La Guayras, Caracas, and the anal Zone. Of course, we traveled in an ectrically equipped ship and at each port e found that the electrical engineer had receded us and provided lights, railways, imping stations, and refrigeration.

As the delightful cruise drew to a close we iought of the many Institute conventions e have been privileged to attend, the 1937 ew York convention in particular; and ie conventions of the future, the 1937 [ilwaukee convention in particular.

The 1937 winter convention seemed one the busiest, most stimulating, and most teresting that we have attended. Our ily regret is that every member of the ornization could not be there. The outanding feature was the presentation of ipers at the 14 technical sessions. There a mental stimulus through the authors' personal presentation, which cannot be realized by reading alone; and the resulting discussion is sometimes more valuable than the paper itself. Frequently the discussions were continued outside the meeting long after it had closed. Next was the opportunity offered, through the many inspection trips, for observing the most modern electrical installations. The presentation of the Edison Medal to Doctor Alex Dow, outstanding pioneer and president of the Detroit Edison Company, was a memorable and impressive occasion fittingly climaxed by an inspiring address from Doctor John C. Parker, vice-president of the Consolidated Edison Company of New York, Inc.

During the convention an unusual number of committee meetings filled every available room at headquarters. Carefully arranged, these committee meetings appeared to stimulate rather than detract from the interest in the technical sessions. Because of the committee meetings many were present who otherwise would not have been able to attend. Some committees met on the first day, presented their recommendations to the board of directors at its meeting on Tuesday, and at a second meeting late in the week took steps to initiate the activity which had received the board's approval.

It has become customary to hold the meeting of the national nominating committee during the convention week. This plan brings to the convention a prominent, enthusiastic, and active Institute member from every District. Opportunity is also offered to each member of the nominating committee to consult many other Institute members relative to the most important work of the nominating committee.

For the first time in our history, the board of directors devoted 2 afternoons in a single week to the affairs of the Institute.

Those who attend a New York convention see our efficient headquarters' staff in operation and realize what a busy place headquarters is.

Each day I overheard or took part in discussions relative to Section activities, Section membership, Section management. Plans were discussed and final details completed as to visits by national officers to the various Sections. Ideas were exchanged and enthusiasm given and received.

Last and not least acquaintances were formed and strengthened, friendships renewed, new friendships started. The electrical engineers were meeting on a common ground and with a common purpose.

Great credit is due Chairman C. R. Beardsley, and all his committee chairmen, and the members of the committees for the excellent handling of all of the tremendous amount of planning and detail so essential to a successful convention.

The members of the AIEE enjoy and profit by convening. This year 4 invitations were received for the 1938 summer convention and one for 1939. It was indeed difficult to choose between these invitations, but Washington, D. C., was finally selected since the Section there is very active, has not previously been our host, can offer unusually adequate accommodations, and is located in a city we would all like to visit.

The next national convention will be at Milwaukee, Wis., next June, cooled by the breezes from Lake Michigan. In last December, I visited the hotel that has been selected for convention headquarters and saw one of the finest convention floors to be found in this country, with every provision for assembly and meeting rooms. The Milwaukee committee was organized over 7 months ago and has planned an unusual convention of broad general interest. In spite of a recent story in *Saturday Evening Post* I believe in conventions of the type we hold and wish the author of that story might be with us in Milwaukee and observe how a real engineering convention is carried on. I hope to meet a large number of you at Milwaukee.

Improved Lighting in Passenger Vehicles

THE SCIENCE OF SEEING differs somewhat from the science of vision with which most of us are generally familiar. The science of vision is a relatively old subject and deals with the eyes, their functions and limitations. The science of seeing, however, treats the human being as a seeing machine, particularly as regards its behavior, efficiency, and welfare.

Years of research, from which grew this new science, definitely prove that lighting values and conditions of the past, and especially in the realm of transportation, are totally inadequate for what may be termed comfortable or easy seeing. Such ideas or beliefs as that 4, 6, or even 8 footcandles represent adequate lighting have been literally blasted.

It is obvious that of those passengers who attempt to read while patronizing transportation systems today, all but a very small percentage are 20 years of age or more. A recent survey indicates that of those at the age of 20 years 23 per cent have defective eyesight; at age 30, 39 per cent; at age 40, 48 per cent; at age 50, 71 per cent; while at 70 years of age 95 per cent have impaired eyes.

Furthermore, investigations covering several occupational groups show that in the farmer and laborer class, where work is usually carried out under daylight conditions only (500 to 8,000 footcandles), less than 20 per cent have defective eyes. In the carpenter and painter groups, a percentage of from 20 to 40 is noted; the machinist and printing occupation from 40 to 60; housewife and textile worker from 60 to 80; and in the drafting and stenographic field from 80 to 100.

The foregoing is mentioned for the purpose of bringing out the great need for more and better lighting, not only for the purpose of aiding those eyes that are already defective but also to serve to protect those millions of eyes that are as yet unimpaired.

It is encouraging to note that recently the several transportation agencies, in their earnest efforts to serve the needs of the public, have begun to give serious thought to this subject of lighting.

The modern day coach shown in figure 1 is indicative of the strides being made by the more progressive railroads. It is lighted by means of a combination indirect and direct louvered system. The indirect, which provides a low general illumination, is delivered from a single row of lamps spaced along the center line of the ceiling. Direct view of these lamps is prevented by the unique baffle which not only directs their light toward the ceiling but also serves as the duct for air conditioning.

This system is supplemented by individual seat-lighting fixtures of the direct type properly louvered, which are incorporated within the rolled edge of the continuous basket or baggage rack. Approximately 12 footcandles are obtained at the reading plane. About 5 watts per square foot of floor area are provided.

No discussion of rail transportation would be complete without presenting some of the lighting treatments which are being incorporated in the new Diesel-electric streamline trains. Figure 2 shows a portion of a truly modern observation lounge car. The lighting here is delivered from a semi-indirect open-top louvered-bottom aluminum trough containing small-wattage lamps located on approximately 7-inch centers. The general illumination is secured by light reflected from the ceiling and the reading-plane illumination derived mainly from the direct light from the lamps. The front edge of the trough and the transverse louvers in the bottom of the trough protect the eyes of those seated from direct view of the lamps. Approximately 12 footcandles of illumination are provided at the reading plane.

Another example of modern train lighting which is quite worthy of note is that of a recently built Pullman sleeping car shown in figure 3. The general illumination

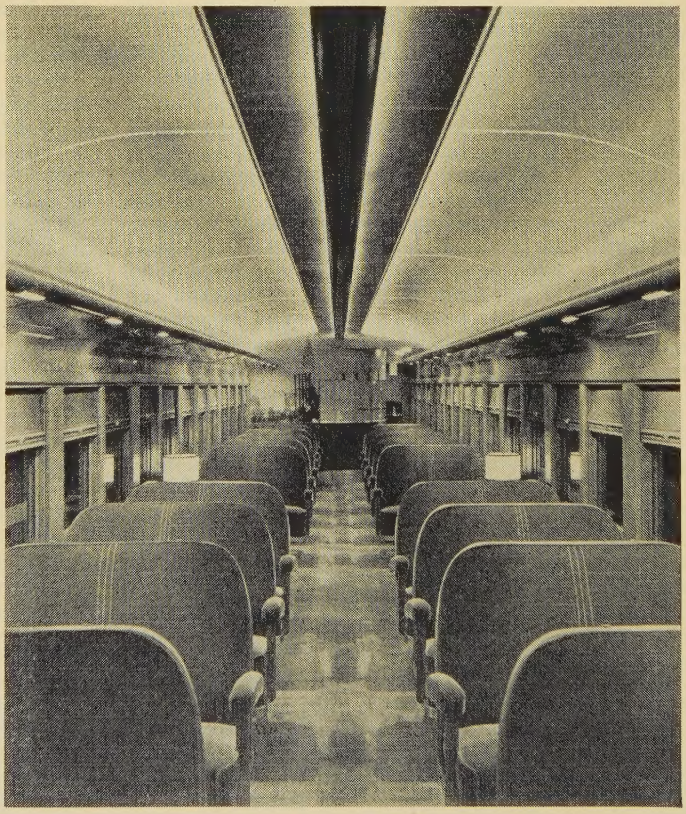


Fig. 1. Combination indirect and direct louvered lighting systems in a modern stream-lined day coach

Indirect lighting system consists of 15-watt 60-volt lamps located above air-conditioning baffle; individual seat lighting is from 60-watt 60-volt tubular lamps located above transverse louvers in edge of bag rack

An article written especially for ELECTRICAL ENGINEERING, based upon an address by H. H. Helmbright of the incandescent lamp department of the General Electric Company, Nela Park, Cleveland, Ohio, before a meeting of the transportation group of the New York Section, April 9, 1936; recommended for publication by the AIEE committee on production and application of light.

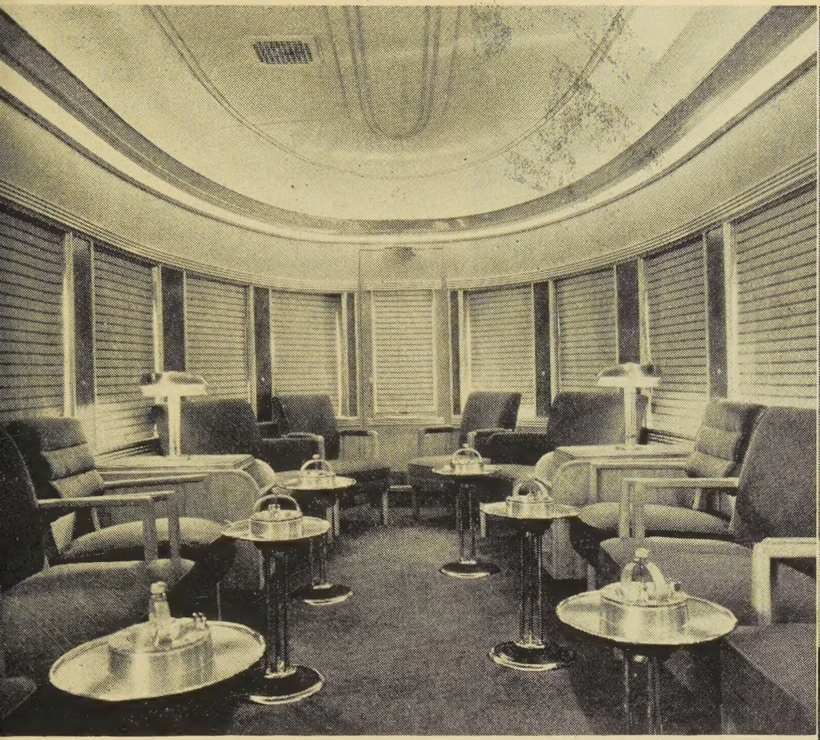


Fig. 2 (above). Semi-indirect louvered-trough lighting in an observation lounge car

Each trough contains 10-watt 32-volt lamps spaced 7 inches apart

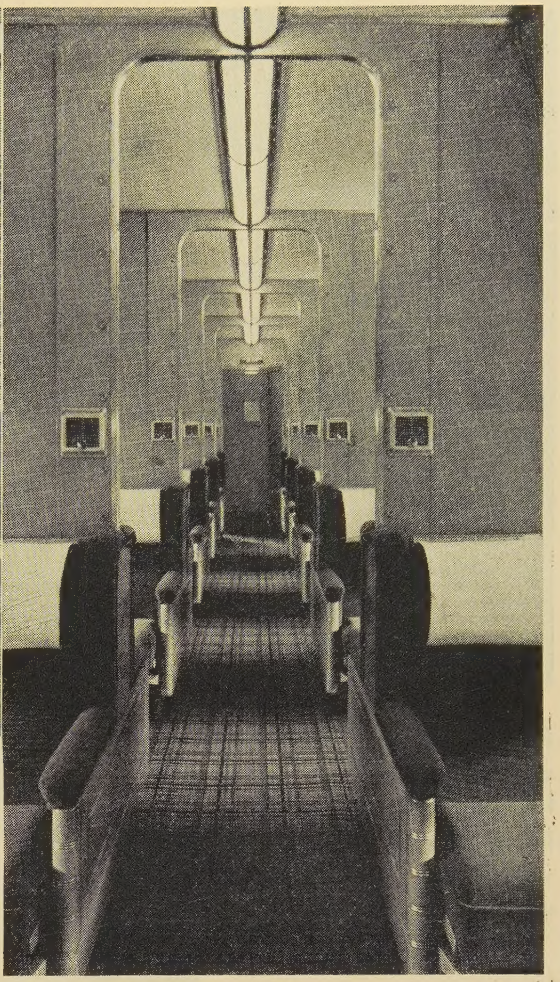


Fig. 3. A modern Pullman sleeping car lighted by central lighting system and new berth-lighting fixtures; night-lighting circuits are incorporated within fixtures

The ceiling fixture of the continuous direct type contains 10-watt 32-volt lamps on approximately 7-inch centers above semicylindrical flashed opal glass; small 6-watt blue-coated lamps are provided for night-lighting use

furnished from a continuous trough of the direct lighting pe, in which are also incorporated the air-conditioning itlets. The semicylindrical glass sections diffuse the ght from the single row of lamps which are mounted ithin a reflector recessed into the ceiling. A night lightg circuit consisting of low-wattage blue-colored lamps is so included to facilitate reading the section numbers and so to insure safe passage along the aisle after berth secons are "made up" for occupancy.

A new type of berth-lighting fixture furnishing approxiately 10 footcandles is installed at both ends of the ction. This fixture is also equipped with the blue nightghting feature.

Train-lighting systems of the totally indirect type, though possessing many virtues, are rapidly being abanoned, partly because of their extremely low efficiency rom 8 to 15 per cent) and the rapid depreciation of their flecting surfaces under railroading conditions. Furtherore, a totally indirect system that would produce footndles in keeping with modern standards would probly produce uncomfortable ceiling brightness that would annoying to the eyes.

Strange as it may seem, the electric street-railway dustry, which until recently seemed doomed to be reaced by the motor bus, has taken a "new lease on life." e industry has joined with the various manufacturers electric railway equipment in staging a "comeback." distinctly new type of vehicle has been developed that fers in many respects from the general conception of e street car. Lighting, consisting of a relatively large mber of bare lamps studded throughout the car ceiling, has been replaced by more efficient and less glaring systems giving the passenger from 10 to 20 footcandles of lighting. Figure 4 shows one type of street car that has been equipped with the semi-indirect louvered trough producing an average of 18 footcandles throughout the car. This replaced a direct system delivering from 8 to 10 footcandles at the reading plane.

Another continuous louvered system in which the greater portion of the light is directed toward the reading plane has been produced and installed in trolley busses (figure 5). This design also delivers approximately 18 footcandles at the reading plane, but permits a spacing of lamps 50 per cent greater than in the semi-indirect trough shown in the street car (figure 4).

Other modern and efficient types of lighting systems recently produced have fixtures of the direct type placed directly above each transverse seat. In general, the design is such that accurate control is obtained, thus preventing direct glare from reaching the reader's eyes. This control may be secured by means of lenses or by glass-

Fig. 4 (above). Street car equipped with open-top louvered-bottom aluminum trough for lighting

Trough contains 30-volt 1-ampere automatic-cutout lamps spaced on 10-inch centers

Fig. 5 (right). A modern trolley coach with recessed louvered trough for lighting

Trough contains 30-volt 1-ampere automatic-cutout lamps spaced on approximately 15-inch centers

enclosed reflectors. The lighting efficiency of these systems, in terms of foot-candles at the reading plane, is slightly greater than that obtained from either the semi-indirect or direct louvered trough.

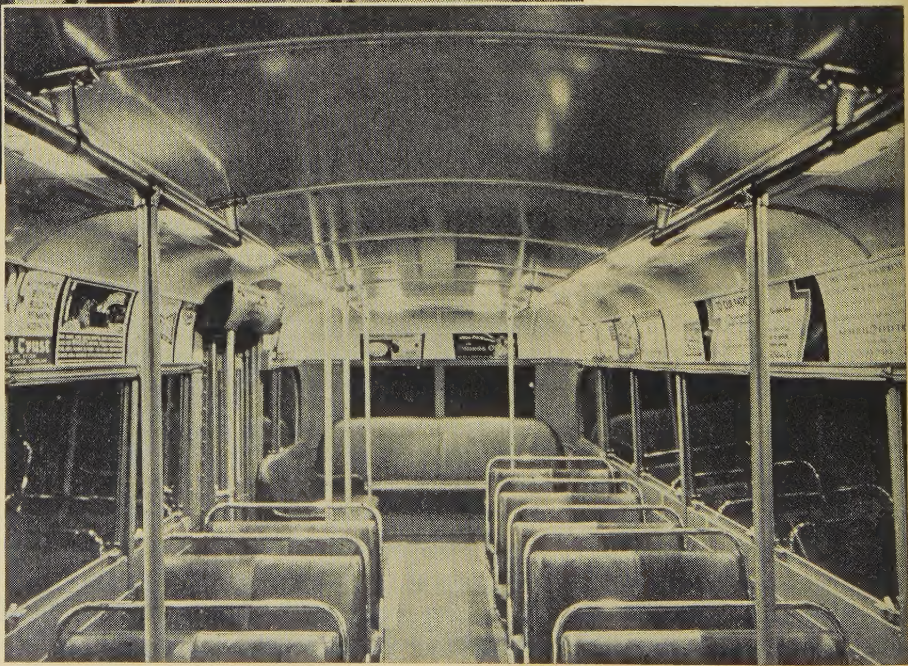
The gasoline-motor-coach field, desiring to maintain its present position in city transit and also to compete successfully with the new-type street car and the electric trolley coach, is making rapid progress in the art of lighting. Power supply has been increased from approximately 150 watts to 750 watts and in extreme instances to 1,200 and 1,500 watts. Present day practice results in one fixture containing a 21-candlepower lamp being placed above each transverse seat or its equivalent. Until recently, one fixture containing a 15-candlepower lamp and in some cases only a 6-candlepower lamp, placed above each alternate seat, was considered adequate.

Here again the lens or the reflector design is used to obtain high output efficiency and to avoid objectionable glare. By the use of the 21-candle power lamp as mentioned, it is possible to obtain approximately 10 footcandles at the reading plane. In figure 6 a good example of modern motor coach lighting is shown.

Judging from the intense interest in illumination that is being displayed by transportation officials, it is believed that the time is not far distant when transportation lighting conditions will be quite in keeping with those obtaining in other fields where usual seeing tasks are performed. Lighting still remains one of the most important tools available to the transportation field in furthering the development of passenger travel.

Fig. 6 (below). Modern lighting in a motor coach

Open louvered-type fixtures are used with a 12–16-volt 21-candlepower lamp in each

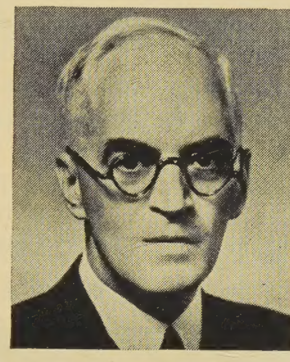


Power and People

By JOHN C. PARKER
FELLOW AIEE

The application of technical advances to the welfare of mankind is held to be the true contribution of engineering to civilization, rather than the advances themselves; power together with tools to use it, and not power alone, led to American industrial development. More than merely the availability of large amounts of power is necessary in order that standards of living may be raised, and maintained.

BECAUSE I know a little more about power engineering than about any the other varied aspects of ır profession, it seems suitɔle in large part, in attemptg an inquiry into the social lations of our more mechanił performances, to use some pects of the arts of energy oduction and distribution as pical rather than as the exclusive subject atter of our discussion. I suspect that e are in essential agreement as to all at will be said here this evening. Cerinly I do not believe that I shall be inging any new ideas to you, nor is what have to say any recently inspired prodt of the vigorous or violent sequence of ents in this decade. I hope to suggest r your reconsideration things already ell known to you, but which, under the essure of necessity in material things, l of us are likely to get into a wrong erspective or even entirely to forget.



Doctor Parker

I approach a discussion of the relation of technology to ımanity with a greater hesitation because today it ems increasingly convenient to seek implications behind plicit terms. Will you accept my assurance that no ggestions are intended beyond the things actually dis ıssed? Whatever applications to engineering conduct ay be suggested, it would be most improper before a ciety of professional engineers to attempt to preach at her elements in society. I think it may fairly be said at however vivid our professional imagination and hower sound our social conduct, we engineers are not characristically possessed of an extraordinary degree of social ıagination.

This comes about through the very nature of our traing and more particularly of our engagements. Probably ere is no calling more definitely social in its character an is that of the engineer. The engineer does not live life of isolation but on the contrary works with and rough other men. His work, whether it be in research design or construction or production or commercial stribution, involves understanding of, and adjustment and co-operation with other men. A community of ort is necessary to the complete realization of his underkings. He has then a high reality of contact within a sely articulated social unit. In this his work is defiely more social than that of the physician or of the vyer or of the minister of souls or of the exponent of the ative arts, each of whom, in a large degree, works as an individual. In that very fact, however, the engineer has at once a satisfaction and a limitation of his social contacts. With other men, largely of identical or at least of closely related interests and limitations, he finds satisfaction for his desires for human contact and such satisfaction easily enough so preoccupies his time that he can easily fail of social understanding of the people whom his profession serves or of the social significances of his own works.

The profession perhaps is not unlike the cloistered monastic orders, living their intensely intimate and interrelated lives, out of touch with the world immediately about them. The physician or the lawyer, on the other hand, carrying on an individual practice even with people in their less normal temper or physical state, does have of necessity a vividness and reality of contact with people other than his coprofessors, and properly to do his work must have the imagination broadly to interpret their lives, their needs, and the significance of his professional efforts in their behalf.

These individual service professions do come closer to the people served than do we.

In consequence of engineering remoteness, we perhaps become obsessed with the technical beauties and interests of our work and with the human problem of co-ordination with our fellows in creation and miss some perspective of how our works touch on the larger interests of society. Not infrequently, it seems to me, we have missed entirely the large significances of engineering and perhaps as frequently, in the fashion so common among self-deprecatory people, we have put up a certain defensive insistence on importances which simply do not exist.

If at both extremes the world has taken us at our own depreciated valuation, there can be little complaint on our part, nor can there be any great surprise if the less ponderable and less obvious values in us and in our works are not spontaneously accepted. Of course, it hurts our finer professional sense if people think of us as mere technicians of unimportant arts, whether the niceties of sound engineering analysis are appraised merely as necessary contributions to a socially unimportant technique, or, as might be inferred from lay references in the news columns

An address presented January 27, 1937, upon the occasion of the presentation of the Edison Medal, during the AIEE winter convention, New York, N. Y.

JOHN C. PARKER is vice-president of the Consolidated Edison Company of New York, Inc.

and in the advertising space, the engineer is esteemed as only a slightly sublimated form of mechanical handyman.

On the other hand, when laymen, editorial writers, and public officials agree with us in adulation of our works and hail engineering achievement as the be-all and the end-all of social progress, it is easy for us smugly to agree with what is at once too narrow a conception of the value of our work and too great an emphasis on its place in a world of human beings. When such a philosophy becomes characteristic of a nation or of a period, we may well be in desperate danger.

There is not exaggeration in the belief that a disproportionate acclaim is given to mere mechanical achievement.

A few days ago an eminent traveler expressed his belief that the hazards of life were great in this country because we were the most highly civilized, the cause or the evidence of our civilization being, in his mind, the fact that we have so many machines. The extraordinary thing is that that remark did not produce any comment in disclaimer of mechanisms as either an origin or an evidence of civilization, though in all truth an essentially barbaric people might produce as great engineering works as did the uncivilized Romans in their crudest period of material well-being.

The truth is that our engineering activities are not necessarily evidences of civilization, nor, although they are almost essential, are they by themselves the means to civilization. On the contrary, when pursued too narrowly they can be destructive of the real values in living.

The engineer does not need to arrogate to his works an undue or an undeserved importance in order to find a splendid justification for his calling. Reasonable social awareness will disclose paramount reasons for a fine professional pride.

These lie in 2 categories, of which the first, and the one which can be a most extraordinary contribution to the welfare of the race and to the progress of our times, lies in the engineer himself. I need not develop at great length all those characteristics which most mark the men who have been the pride of our profession.

The engineer who is an engineer approaches his work without bias and with a mind freely open to conviction. He cannot be a special advocate and remain in any professional sense an engineer. Whatever may be the limits of his vision, he does at least possess a fine objectivity in his imagining. For him no sentimentality or wishful thinking will conjure up visions different from the world of things as they are. His creative thinking is the finer ability to project the observed facts of today into principles and rules of conduct and a clear picture of possibilities that are certainties because their origins are actual.

"Extra hours redeemed from darkness"

The pure lines of the catenaries spanning the Golden Gate and the rhythmic proportions of their supporting towers are a orious outward expression symbolic of the courage and dignity of the conception and of the long period of painstaking and anxious preparation"

Because of his freedom from bias and the objectivity of is thinking, he must of necessity be possessed of integrity, nd because he is intellectually honest and open-minded e is tolerant of judgments that do not conform with his wn, while courageous and firm when he gets out of the eld of opinion and into that of fact.

If as a profession we can gain acceptance by the world the personal qualities of the engineer as freely as it has een willing to accept his works, society's debt to us will e enormously greater.

Secondly, the works as well as the character of the ngineer give him a right to claim a great place in the teem of mankind, not for the things themselves but r these things in their relation to civilized living and inking. There is a profound and important difference ere and one which in practical effect needs the most pains-king care to avoid damaging, if not fatal, error. The stinction is that between sterile virtuosity and a vital tistry which reaches into the very fibers of men, or again is not much different from the contrast which exists etween a flippant self-indulgence in metaphysical acro-atics and the beneficent philosophy which gives us God, eedom, and immortality.

To get down to cases, the production of the electric ght or the development of an industry about it means othing or less than nothing except as it may be related an over-all improvement in the welfare of mankind. ruly this art has enabled men of good purpose to live eir lives in greater security and nobly to employ extra urs redeemed from darkness. I think it is not at all reasonable to claim that the writing and the wide blication of fine literature have tremendously been mulated by the possibilities created by this one art of e engineer.

The important thing to recognize, however, is that the technical achievement has gained much of its significance as an adjunct to the arts. The production of a minute lighting unit is only a slightly more advanced form of achievement than that of the man who writes the Lord's Prayer within the space of a postage stamp, but the production and adaptation of such a luminant for the nicety of a surgical operation becomes a service very real indeed.

What is important here is, of course, how people use the power that we place in their hands. Quite as easily, if humanness of feeling and cultivation of mind do not go along with our technical possibilities, these can become curses rather than beneficences.

So, if we please, the telephone and the telegraph, interesting inventions, marvelous expressions of research and energy and co-operation and faith, still remain things of little importance except as they bring people into more familiar intercourse and closer understanding one of another, except as they remove the narrowness of isolation and contribute to the genuine happiness and welfare of men.

Our great railroad systems would not be worthy of the sacrifices that have gone into creating them were it not for what they have done in enabling men to push out into freer and more intelligent lives and to grow, and themselves, through the agencies of transportation, to be of service to other men in distant parts of the world. The automobile merely as a device for speed and restlessness would be a wonderful mechanical achievement and a curse to the race, but men have been able to relate themselves to, and to appropriate, these engineering achievements for a more decent living and as aids to something more than merely material happiness. In all these real values our engineering works have gained their significance be-

McGraw-Hill

"The power engineers of this country have done, as the engineers have done in practically every field of American endeavor, a glorious job"

cause of uses ancillary to other functions of living, and doing so have become vastly greater even than the engineers conceived.

I would not be thought for one moment to be deprecatory of the intrinsic romance of engineering achievement, nor would I concede that engineering structures are deficient in beauty and in nobility. The pure lines of the catenaries spanning the Golden Gate and the rhythmic proportions of their supporting towers are a glorious outward expression symbolic of the courage and dignity of the conception and of the long period of painstaking and anxious preparation. The spiritual qualities of such an engineering work may be different from those appearing in a work of poetry, art, or music, but because of difference they are no less present. All one would say is that in both the engineering and the less rigorously scientific fields of the other arts the real beauty, the real romance, the real nobility come from interrelation with life.

Indeed such things as we have spoken of—the service which engineering works render to life, and the spirit and the character with which the engineer approaches his profession—are the stuff of which the arts and philosophy are made.

Even in the narrowly technical sense, our portions of the arts are portions and not the whole, and a great deal of disappointment and some social disturbance can be avoided by recognition of that. A specific instance may illustrate the way in which absence of realistic social awareness may lead to dangerous implications.

There is a general public interest in the problems of power production and distribution that is way out of proportion to any significance even so important an art has in the affairs of men. This would be puzzling if it were only a recent phenomenon. It is not the less disturbing because of the fact that it has been developed over a period of years by an ill-considered but perfectly honest enthusiasm which has mistaken simultaneity of occurrence for a relation of cause and effect.

When in the middle and late '20's the rest of the world was suffering the economic aftermaths of war and we in this country were riding on the full tide of what we believed to be prosperity, we explained to ourselves that we had so many horsepower back of the elbow of every American working man. The *Daily Mail* sent an English commission to discover that mechanically developed power was the great secret of American prosperity; the Soviet Union initiated its series of 5-year plans with an emulation of the great American electrical industry, while Fascist Italy sought to develop the backbone of the peninsula through a superpower system. I have no quarrel with these things, but I had then and have today a profound disagreement with a wrong emphasis.

The power engineers of this country have done, as the engineers have done in practically every field of American endeavor, a glorious job and they continue to do so. We have produced and distributed a superlative quality of service at extraordinarily low prices. It has been made available to the largest feasible percentage of the population and is used in a degree almost unrivaled throughout the world. Yet this much vaunted power use did not suffice to keep us from plunging headlong and with characteristic American vigor into the world depression. There is no reasonable basis for believing that power development on an even greater scale in this country is going to pull us into the prosperity which the secret of American well-being a dozen years ago was not able to preserve for us. Claiming all the territory in sight at that time was a result of rather superficial thinking. Power engineers today would be foolish if they accepted the responsibility implied in the theory that dynamic development is a thing precedent to social or economic uplift. Acceptance of any such idea will simply find the power people again discredited.

Let us see what the actual fact is in regard to the place of power development in the American industrial picture of the predepression days. There was more power at the

ommand of the worker in industry than existed anywhere lse in the world. It is so rudimentary as to be almost rite to say that the factory worker did not take x kilo-vatts into his hands and apply them directly to a bunch f steel ingots and have a freight car emerge from the rocess. Not only that, but American industry did not et out with the idea of trying to apply power to industrial roduction and thereafter discover the means for utilizing ower. Ingenuity, energy, and the courage of conviction roduced the machine tool, the turret-lathe, the auto-natic screw machine, punch presses, and drop hammers. These called for power and for power in ever increasing uantities. Without an ample supply of dependable ower at modest prices we should have had carefully to estrict the use of power in manufacture and the hand rocesses would have persisted here as they have else-vhere.

The power industry saw a commercial opportunity and bserved a social responsibility. Its place in the picture s sufficiently great in that it did supply that which was ecessary to the operation of the machine tool.

Neither power nor the machine tool without the other ould have established the American methods in industry, or could both of them together have done very much vithout the development of elemental metals and of alloys nd plastics which should lend themselves to the processes f quantity production. These again would have been of ittle use had it not been for the development of design lirected quite as much to the working of modern materials hrough the power driven machine tool as to the function-ng of the product after it was made. An entirely new echnique of design was called for, a technique superb in ts philosophic simplicity, in its intellectual straightfor-vardness, in its impatience with artifice or dissimulation. But neither design for production, nor modern materials, or machine tools, nor the power to drive them, or any of hem in combination would have been of the slightest use vithout one of the greatest contributions that America as made to industrial progress. That contribution may e described in any one of its aspects as the use of tolerance imits, interchangeability of parts, standardization, the se of limit gauges. Again there is a whole philosophy f moral conduct suggested in the conception of units nterchangeably and excellently adapted to correlation vith other units for the production of a whole, no one eing required to be perfect but each one being limited to tolerable excess or deficiency from a working ideal.

When all of this is said and done we have not yet quite pproached the full story of the place of power in the busi-ess of satisfying the needs of the people. Engineers well nderstand that the process of industrial production, vhether it be in machines or textiles, in meats or maga-ines, is a function of quantity. Below a rather large ninimum an enterprise cannot develop the methods of nterchangeability which make the machine tool tolerable r which bring power into the service of the workman. Enterprise and courage and a reasonable assurance of uccess are necessary as inducements to the people who isk their savings in enterprises which may become obso-ete on a whimsical turn of fashion or impotent through a major economic disturbance. This is the part of the entrepreneur who, in a very real sense and working outside the fields of power development, has been necessary to the development of the industrial uses of power in this country.

All these elements put together might have accomplished nothing had it not been for the superb achievements in distribution which have brought the end results of industry to the final user.

Some engineers and a certain sentimental type of social scientist occasionally deprecate the function of commercial distribution and find it quite without use. I am not at all sure that advertisers and merchants are perfect or even intelligent in their processes, but I do know that it is something to have persuaded several millions of people to want a new agency of transportation and to promote such construction of roads as would make it possible for those millions to reorganize their living about an automobile, and to persuade those same millions to accept an at least currently standard type of machine rather than individualistically to insist on going without through devotion to the fetish of tailor-made cars.

I am not permitting my enthusiasm to enlarge the importance of the nonengineer in this whole sequence of development. I know perfectly well that salesmen and capitalists did not in the first instance plan all that they have produced any more than the power engineer, when

Ewing Galloway

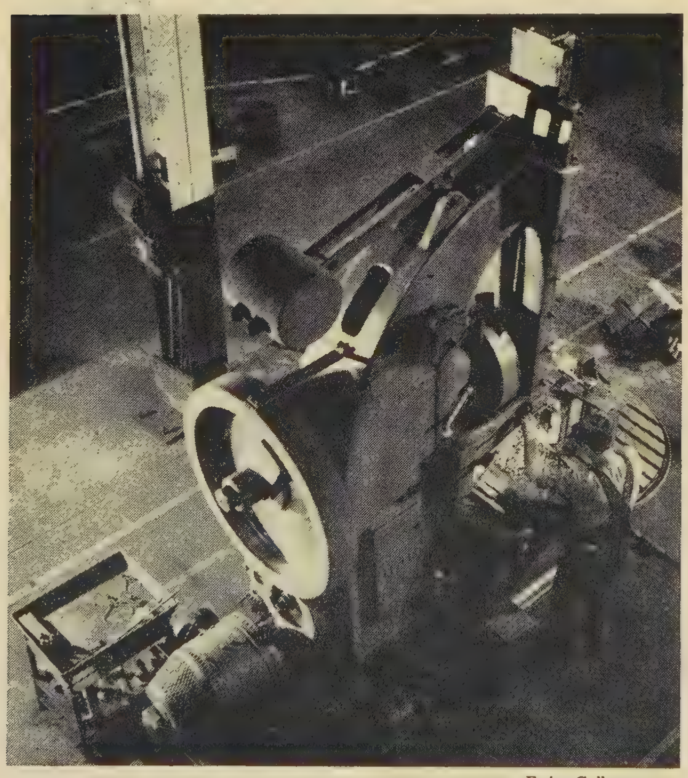
"Power at the command of the worker in industry"

he developed his induction motor, had any idea of applying it to the gargantuan rolls of a steel mill. I am simply saying that these people, like ourselves, recognized facts as they came along and had imagination to build from them a little at a time until from gradual progress there developed a philosophy of commercial existence. Indeed, had they tried to devise an economic or industrial system out of their own imaginings they would probably have come off very badly.

The machine tool itself was a product of necessity. It probably never would have come into at all substantial use had it not been that the cost of supporting the typical American workman made necessary some means tremendously of increasing his productivity.

Note well that every one of these elements which we have sketched has been essential to modern industrial life as we know it; even more than that, has been essential to modern nonindustrial living. Our enthusiasm for one of these elements in which we may happen to be particularly interested—let us say power—should not run away with our sense of proportion. On the contrary, it seems to me that our pride in our own service becomes greater if we have an adequate picture of where it fits in as an essential and considerable element of something enormously bigger than itself.

We need not be at all deprecatory of the importance of our power developments as service to the home or to the farm merely because we may be realistic in our apprehension of the fact that many other things enter into life and that the life is more than meat and the body more than raiment. It is understandable, though not by virtue of that at all defensible, that the specialist should develop an unrestrained enthusiasm for his particular field of human endeavor and that his extreme loyalty might communicate his zeal to others. What is not perhaps quite so clear is that economic, social, and political injuries may result from these widespread and exaggerated enthusiasms. Not alone as a matter of humane consideration, but in self-defense against the reactions of disappointed hope, we must be at pains not to arouse desires that we cannot gratify or which, gratified, will be found not all that the body or the soul can crave.



Ewing Galloway

"Neither power nor the machine tool without the other could have established American methods in industry"

Energy available as a contribution to carrying on the amenities of domestic life is, beyond question, almost, but not quite, indispensible and a long, long way from being all-sufficient. Let me qualify this a bit. Energy in some form or other is, of course, completely necessary to human existence. For all of the necessities of life there are substitutes for those forms of energy with which you and I, as electrical engineers, are most concerned, and in some applications these other and more ancient forms may come very close to the excellences that we can offer, if indeed in some respects they may not offer facility or charm rather greater than can be developed by electric power. With this qualification, may I return to the statement that our special form of power is almost indispensible to the convenience of modern living.

Unfortunately the ultraenthusiast paints so vivid a picture of the domestic comfort created through the power agency that people in all simplicity but in no less great sincerity come to believe that electric power is at once necessary to living and a solution of all the mechanical problems of the home. I have even read claims not dissimilar to those on behalf of the x horsepower at the worker's elbow—namely, that electricity can take all the guess work out of cooking and the drudgery out of domestic life.

It is perhaps reasonable to suspect that a good deal of the current abnormal interest of the people in power problems may be due to their persuasion that this, that, or the other overly exploited device is essential to civilized living if not a sure cure for all of the difficulties thereof, instead of being, as in many cases it is, a most remarkably adept contribution thereto.

So, if you please, a profound conviction of the value of extending to the farm the power use which has been so common in industry may run away with itself.

More than 25 years ago, as chairman of the committee on electricity on the farm of the association of the industry with which I was identified, I had occasion to know those early efforts at a broadened use for power. My own company in the rich farm country of western New York discovered at once the values, the difficulties, and the limitations of farm supply from contiguous distribution circuits. From such a realistic background, I have observed with much satisfaction the various well-planned efforts which, in this country of vast subeconomic areas, have saturated every section whose intrinsic economy at all approaches the productivity or the population density of western Europe.

On the other hand, I note a marked parallel between

Ewing Galloway

Here "rural electrification is feasible and highly developed"

power use and the human relations. Farm use is least in those states where farm tenancy is common and progressively greater until we reach an extraordinary saturation in the lean, rock-ribbed, stubborn, but user-owned farm country of New Hampshire.

This and similar human factors make it important that we note certain limitations in this as in other desirable fields of power development.

In the first instance, the farm is not a quantity-production factory. Its functions are biologic and not mechanical, and the conditions are not repetitive nor even precisely cyclic. The economic contribution which power makes in industry cannot reasonably be expected to have any parallel in farming. The economic welfare of the rural regions is much more intimately concerned with soil quality and selection of strains and with plant and animal pathology and with market problems and transportation than with the application of mechanical power.

Success of our endeavors in industry does not necessarily indicate that we can contribute equally richly to agriculture.

Rural electricity, of course, can contribute markedly to ameliorating the conditions of rural life, but here, as in claiming too much for the economic values of farm electrification, we must be reasonably careful that we do not arouse hopes that can only result in frustration. Strangely enough, it seems not to be popularly recognized, nor even to be realized by those better informed technically, that the refinement of running water in the home is not, excepting in the least degree, related to electric wires along the highway. Yet a thumbing of the pages of any mail-order catalog will bring vivid conviction of the fact that pumps, piping, and fixtures not only are the essence of that particular evidence of civilization but that they are somewhat easily to be had. Until the essentials of sound sanitation are sought by the rural population one wonders at times about the value of the electric circuits.

The most distressingly backward of our rural communities do not in all conscience need electric power, either economically or as adjuncts to living, one-tenth as much as they need many other things closely at hand but still frightfully difficult of attainment within a farm income restricted so narrowly as to make impossible many of the mere decencies of life. I even have a suspicion that when a good job has been done in the way of aiding and advising in an improved agricultural technique and when the intimacy of human understanding offered by education and the means of communication and the means of transportation has itself ameliorated farm living as a result of the economic and social improvements, power lines will almost automatically have become extended to every part of the farm community intrinsically capable of supporting the purchase of the devices necessary to the utilization of power.

Failing of these things, which seem to me to be fundamental, there is grave danger than when experience shows electric service to be unattainable in vast stretches of this country, as it must for a long time continue to be, or when the farmer along the electric right-of-way finds his economic lot and his social outlook not essentially different than formerly, disappointed hopes will vent themselves at the expense of those who encouraged them.

A too-great desire to electrify a type of countryside unknown in those sections where rural electrification is feasible and highly developed has painted a picture of blessings enjoyed by the city dweller and believed by one all too aware of his hard lot to be denied him as a result of deliberate mischief. Thus group suspicion and aloofness have unnecessarily and unjustifiably been strengthened.

What I have been trying to say is that important as is power as an adjunct to factory, farm, and home, it, in and of itself, will not revolutionize life. We are, in our most profound relations, biologic creatures and all the conscious mechanical and technical efforts in the world are small factors in determining the essential well-being of our lives. To the extent that we have made our lives in their superficial details depart from our biologic origins, we find the mechanisms of living important. They will be the more important if our perspective keeps them in the proper relation to the other elements of living and to life itself.

Revision of Standards for Railway Motors

By NORMAN W. STORER
FELLOW AIEE

Higher armature peripheral speeds, better insulation, and improved ventilation of railway motors, together with the rapid development of Diesel-electric equipment for railroads, have made necessary a revision of the AIEE Standards for Railway Motors. The new standards have been adopted as "American Tentative Standards" pending further experience with the new types of machinery covered by them.

THE STANDARDS of the AIEE for railway motors, which for many years have been accepted in the United States as the "last word" and have had an enviable reputation in all other parts of the civilized world, have been completely revised and have advanced to the status of a tentative American Standard. They will be published shortly by the AIEE as "Rotating Electrical Equipment for Rail Cars and Locomotives." Approval of this further revision was given by the AIEE board of directors at a meeting held at Pasadena, Calif., on June 24, 1936, upon recommendation of the AIEE standards committee.

Compiled by sectional committee *C*-35 of the American Standards Association under the sponsorship of the AIEE, these standards are based on many years of experience in the design and operation of railway motors and generators. They are necessary at this time not only to bring the AIEE standards for railway motors up to date, but especially to develop standards for gas and Diesel-electric equipments, the manufacture of which has grown to large proportions.

These new standards have been adopted as "American *Tentative* Standards" because the new types of machinery covered by them have heretofore had no definite standards, and such standards must therefore be developed. It is also important to leave the door open for changes if any are necessary in order to come to an agreement with the International Electrotechnical Commission.

The necessity for bringing the railway motor standards up to date will be apparent when the developments of the last few years are considered. The motor designers have been very active, and have wrought wonderful results. The problem has had the most intensive study, and advantage has been taken of every improvement in materials, processes, new discoveries, and operating experience, with the result that there has been a gradual shrinkage in the dimensions and weight of the motor that is truly remarkable.

Reduction in Weight of Motors

Twenty years ago, the street-car motor weighed in the order of from 40 to 50 pounds per horsepower at the one-hour rating. Today street-car motors are being built weighing from 8 to 12 pounds per horsepower at the continuous rating.

Until very recently, the almost universal practice was to mount one side of the street-car motor on the axle, support the other side on the truck, and gear the armature to the axle through a single train of gears. That practice has been practically superseded for street-car motors by removing the motor entirely from the axle, carrying it on separate springs, or mounting it rigidly on the truck, and driving either through a double-reduction gear unit carried on the axle, or through a "right-angle drive" and a hypoid gear. In either case, the motor is relieved of the pounding of the track, and the track and special work are relieved of the pounding caused by the dead weight of motor on the axle, both results being very desirable.

These light-weight motors together with the light-weight car construction recently developed have given the street railway a new lease of life and made possible the high-speed stream-lined Diesel-electric trains that have recently been so much in the public eye. In the Diesel-electric trains, the weight of the power plant and motors, with the car to carry them, forms a considerable part of the total weight of the train, so that, because the weight reductions outlined apply to both motors and generators, the total reduction is a very important amount.

The question arises as to how this great reduction has been accomplished. There are 3 important factors that are directly responsible:

1. Higher armature peripheral speeds
2. Higher permissible temperatures
3. Better and more ventilation

The output of a given size of motor with a given current capacity increases as the rated voltage and speed increase, to a certain point, then more slowly as the torque begins to fall as the result of core loss and windage until maximum voltage or maximum speed is reached. Hence, other things being satisfactory, it is desirable to operate at as high a speed as is feasible with the gearing available. Higher speeds now used were made possible by refinements in the construction of armatures and commutators, perfect balance, roller bearings, and improved gears.

The rise in the temperature of a railway motor has always been one of the most important, if not the most important, limits. Of course, the motor must be strong enough mechanically and must commutate satisfactorily.

Essentially full text of "Revised Railroad Standard Recognizes Light-Weight Motors, New Designs," published by the American Standards Association in the February 1937 issue of *Industrial Standardization*.

NORMAN W. STORER, retired, Pittsburgh, Pa., is former consulting railway engineer of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa. He has had many years of experience in railway work, and served on the AIEE committee on transportation almost continuously from 1914 to 1936. A biographical sketch of Mr. Storer appeared on page 1405 of the December 1936 issue of ELECTRICAL ENGINEERING.

fter these features are secured, the rise in temperature xes the rating. Hence, any increase in the permissible emperature rise will permit an increased rating. There as been a great deal of experience in the last 20 or more ears with insulation made of incombustible materials uch as mica and asbestos, known as class B insulation, which has convinced the committee that the temperature ses given in the AIEE rules can safely be raised for class insulation. It has, therefore, been increased from 105 p to 120 degrees centigrade rise at the continuous rating, easured by the resistance method. This is a conserva-ve increase based on the large number of motors which ave been operating for years at such temperature rises.

Twenty-five years ago, it was the general practice to perate with street-car motors completely enclosed. ocomotive motors were in some cases cooled by forcing a ream of air through them by motor-driven blowers. he use of fans on the armature shafts, inside of the motor ames, was just beginning. Both of these methods of ooling railway motors have been carried to what appears t the moment to be the ultimate limit and have made emendous increases in motor capacity.

ncrease in Peripheral Speeds

In no class of railway motors have speed and ventilation een carried to greater extremes than in the single-phase otors for the Pennsylvania Railroad for multiple-unit ains and stream-lined passenger locomotives. There, eripheral speeds of armature and commutator are ap-roximately 12,000 and 9,000 feet per minute, respectively, which are about 70 per cent above the speeds of a few ears ago. A veritable hurricane is blown through the otors. The weight per horsepower was brought down elow that of d-c motors designed only a few years ago, which made it entirely practicable equip a single-phase passenger comotive with motive power apable of slipping the wheels with e maximum permissible weight on e drivers and still be able to de-elop the full motor rating at 90 iles per hour.

With such motors as these, the old ethods of rating fall short of the equirements. The continuous rat-g becomes practically the same the one-hour rating because of e rapid ventilation. The one-our rating is of little, if any, value a measure of the thermal ca-acity of the motor, and many gineers have advocated dropping , but while admitting its small alue, the committee feels that it ould be continued until a better easure of thermal capacity is greed upon.

For these reasons, the committee fers a "thermal capacity rating" in the appendix. A number of schemes have been suggested but none has yet had any extensive test. The method proposed will add very little to the cost of the usual tests and should, if properly used, give a good measure of thermal capacity, which is practically the same as over-load capacity. The committee asks for a fair trial of it and the results obtained.

Altogether these rules represent the best thought of the committee that compiled them. The committee consists of 2 members each from 4 national organizations which are vitally interested. They are as follows:

American Transit Association

H. H. Adams (M'19) superintendent of shops and equipment, Chicago Surface Lines, Chicago, Ill.

R. H. Dalgleish (A'11) chief engineer, Capital Transit Company, Washington, D. C.

National Electrical Manufacturers Association

S. B. Cooper, railway sales department, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

M. R. Hanna (A'03) engineer, motor division, transportation department, General Electric Company, Erie, Pa.

American Railway Association

J. E. Sharpley, electrical engineer, The Virginian Railroad, Princeton, W. Va.

Sidney Withington (M'20, F'24) electrical engineer, New York, New Haven and Hartford Railroad, New Haven, Conn.

J. V. B. Duer (A'15, F'29) *alternate*, chief electrical engineer, Pennsylvania Railroad, Philadelphia, Pa.

W. S. H. Hamilton (A'19, M'26) *alternate*, equipment electrical engineer, New York Central Railroad, New York, N. Y.

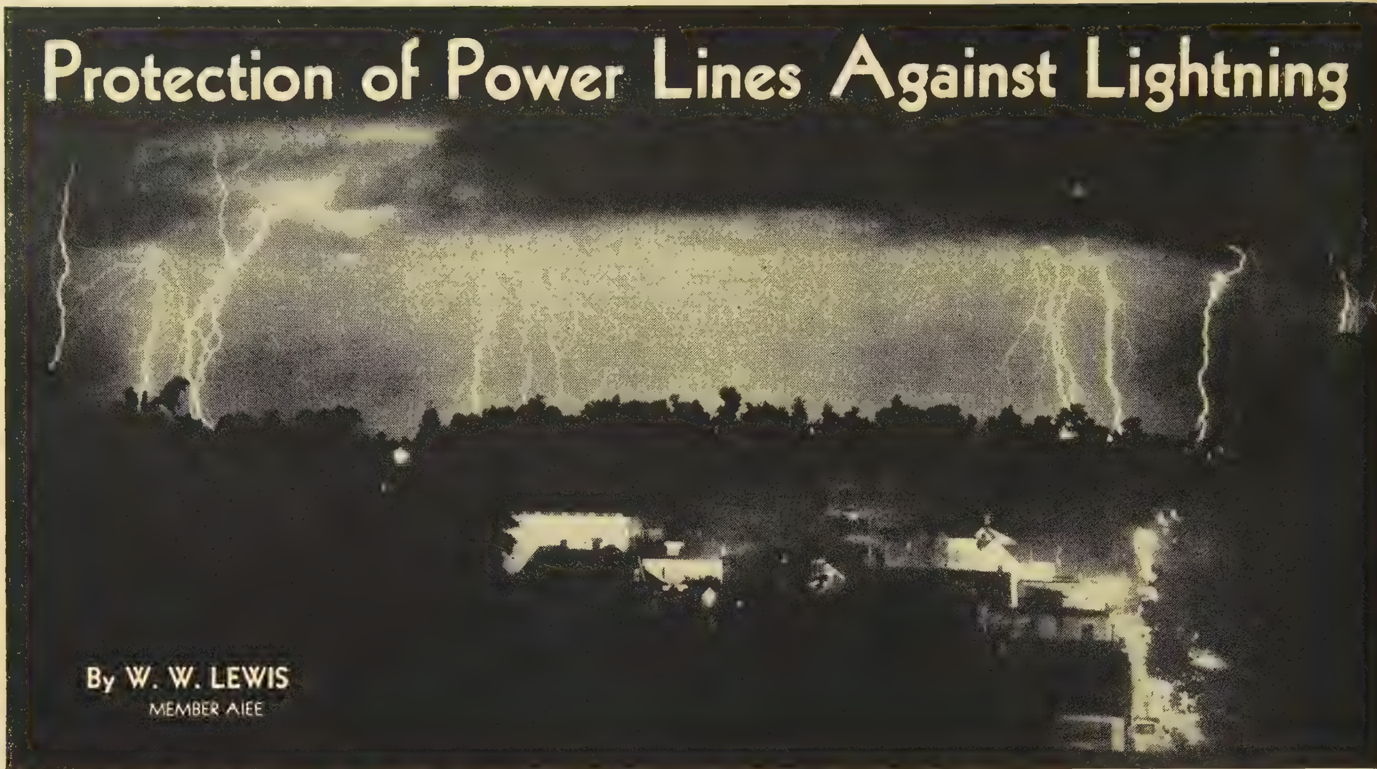
American Institute of Electrical Engineers

E. L. Moreland (A'11, F'21) consulting engineer, Jackson & Moreland; also head of department of electrical engineering, Massachusetts Institute of Technology, Cambridge.

N. W. Storer (A'95, F'13, member for life, past vice-president) *chairman*, retired, Pittsburgh, Pa., formerly consulting railway engineer, Westinghouse Electric & Manufacturing Company.

General Electric Photo

A passenger train of the Pennsylvania Railroad entering Philadelphia; because of their advanced design the single-phase motors with which the streamlined locomotive is equipped require new standards for rating



Protection of Power Lines Against Lightning

By W. W. LEWIS
MEMBER AIEE

A brief review of the fundamentals of the lightning protection problem, and of the various common methods of protecting power transmission lines against lightning, their comparative merits, and their relative costs.

IN THESE DAYS of intense public interest in electricity, the public utilities are making every effort to provide as continuous and dependable service as possible. They are interested therefore in those types of construction and auxiliary devices that will help them maintain a high standard of service.

It is probable that lightning can be held responsible for at least 75 per cent of all interruptions on bare-wire transmission circuits, at least in the eastern part of the United States. The other 25 per cent is caused by such things as wind, sleet, trees, failure of line insulation or structure, failure of apparatus, and mistakes in operation.

The lightning discharge from cloud-to-ground may cause induced or direct potentials to appear between conductors and ground. If such potential is sufficiently high, flashover may result; and if the lightning flashover is followed by dynamic current, tripout may follow.

There are several ways in which the effect of lightning upon transmission lines may be minimized: by the use of (1) overhead ground wires, (2) expulsion protective gaps, (3) Petersen coils, or (4) immediate initial reclosure. In the following paragraphs these methods are discussed in detail.

Line Without Overhead Ground Wires

When lightning strikes a conductor on a line not equipped with overhead ground wires, the current divides and flows in both directions toward the towers. Only a small amount of current passing through the surge impedance of the conductor is necessary to built up sufficient potential to flash over the insulator string.

When lightning strikes a tower, the total current passes down or up the tower, encounters the tower-footing resistance, and raises the potential of the tower above ground potential. This potential is roughly the product of the current and the tower-footing resistance. If this product is high enough, an insulator string or strings will flash over. In some instances the normal-frequency voltage added to or subtracted from the transient voltage may determine which strings flash over. Flashover of an insulator string places the impedance of the conductor in multiple with that of the tower and tends to relieve the potential of the tower and thus may prevent other strings from flashing over.

Where wood poles are used, the resistance to ground is so high that flashover between conductors may take place instead of flashover to ground.

Line With Overhead Ground Wires

One ground wire is usually not sufficient to shield the conductors effectively from direct strokes, either on single-circuit horizontal arrangements or double-circuit vertical arrangements. Two ground wires placed above and mid-

Essential substance of a paper presented at a meeting of the AIEE Philadelphia (Pa.) Section, January 11, 1937.

W. W. Lewis is electrical engineer in the central station engineering department of the General Electric Company, Schenectady, N. Y. He is the author or coauthor of several Institute papers on lightning protection, and is serving on 4 Institute technical committees.

vay between the conductors on horizontal arrangement or ver the outermost conductors on vertical arrangement ave proved adequate in practice to shield the conductors.

When the conductors are properly shielded, a direct troke will strike either the ground wires or the tower. f it strikes the ground wires, the current will divide and ow toward the towers at the ends of the span. At the ower the current will divide again, part passing down he tower and part continuing on the ground wire. The art passing down the tower will encounter the footing esistance, the tower will be raised in potential by the roduct of current and resistance, and flashover will reult if this product exceeds the strength of the insulation. Coupling between the ground wires nd conductors and the normalrequency voltage may sometimes letermine which insulator strings lash over.

When lightning strikes the top of tower, the current divides, part oing down the tower and part going out on the ground wires in both lirections. Again, the part going lown the tower encounters the ooting resistance, raises the potential of the tower above that of the onductor, and may cause flashover f the potential is sufficiently high.

Where wood poles are used with verhead ground wires and down eads, the action is exactly the same s for steel-tower lines, except that he wood crossarm may add extra nsulation and allow the potential to ise somewhat higher before flashver. Where the insulator hardvare is bonded and grounded, the ction of wood-pole lines is identical vith that of steel-tower lines.

Tower-Footing Resistance

From the previous discussion it s apparent that the prevention of lashover resulting from direct trokes to overhead ground wires or owers, depends largely on the ower-footing resistance. Assumng a knowledge of the magnitude f current in towers due to direct trokes and of the strength of the ne insulation, then it is possible to rrive at a limiting value of towerooting resistance for a given line. 'or example, if the highest current xpected is 100,000 amperes and the ne insulation is 1,000 kv, then the ighest permissible footing resistnce is 10 ohms.

Several devices have been used to reduce tower-footing resistance, among which are driven rods, driven wells, ground plates, and buried conductors or counterpoises. Among the questions still to be answered are: the relative effectiveness of a given resistance obtained by 2 different methods, such as driven rods or counterpoise wires; the relation between resistance measured by Megger at low current and voltage and that encountered by lightning current of high intensity and at high voltage; also the most effective length of counterpoise.

Evidence gathered during the past few years attests to the great effectiveness of the continuous tower-to-tower counterpoise wire. A section of line 2.6 miles long equipped with tower-to-tower counterpoise has operated 8 years without flashover, as against an average of 10 flashovers per year in the 3 years previous to the installation of the counterpoise wire.

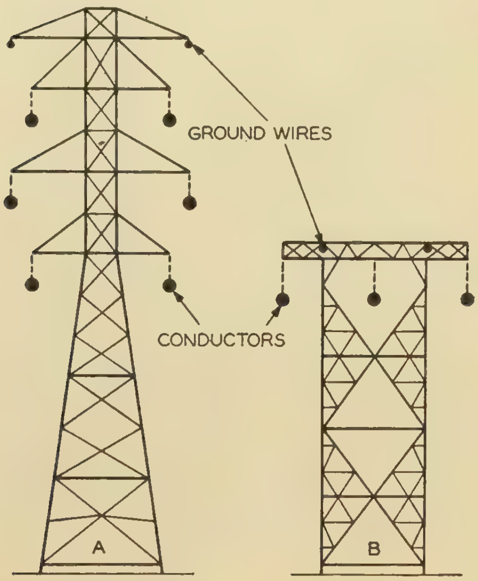
Installation of expulsion protective gaps on 115-kv H-frame line

A continuous counterpoise is, of course, a conductor or conductors buried under the transmission line from end to end of the line or certain sections of the line and connected to all tower feet. Some engineers believe that if the same amount of conductor were used as a radial or crowsfoot counterpoise, where several conductors merely radiate outward from the foot of each tower with no connection between towers, it will give more effective protection.

Short radial counterpoise wires also have improved the operation of lines. On the Glenlyn-Roanoke (Va.) line of the Appalachian Electric Power Company certain towers are equipped with 150-foot counterpoise wires running parallel with the line and from diagonally opposite legs of the towers, with 40-foot wires running at right angles to the line from the other 2 legs. A number of records obtained in 1935 showed the sum of the current readings in the long wires to have a ratio of 4.3 times the current in the short wires; the ratio of the lengths is 3.75. In 1936, a large number of readings on this line showed the sum of the current readings in the long wires to have a ratio of 2.9 times the current in the short wires.

On the Wallenpaupack-Siegfried line of the Pennsylvania Power and Light Company, certain towers were equipped, in 1936, with one 250-foot and 3 50-foot radial counterpoise wires. The summation of readings of currents in the long and one short wire gave a ratio of 7.5, as

compared with a ratio of lengths of 5. Simultaneous readings of current at several different points along the 150- and 250-foot counterpoise wires indicated an almost uniform current distribution along the wires, but with different rates of current connection or dissipation at different current levels. It has been suggested that figures



Arrangement of overhead ground wires to give good shielding against direct strokes, for vertical and horizontal configuration of conductors

of this sort for several different lengths and ratios of length might give some indication of the effective minimum length of counterpoise wires.

Expulsion Protective Gaps

Another way of attacking the problem of continuity of service is to direct the flashover through gaps or tubes set for a slightly lower flashover potential than the insulators, not attempting as in the previously discussed solution to prevent flashover altogether.

The expulsion protective gap is a tube with an internal gap, connected to the line through an external gap, the whole having a flashover potential lower than that of the insulator string. The tubes are selected for the range of short-circuit currents expected. The short-circuit current that follows the lightning flashover produces a pressure within the tube and the arc is extinguished within a half cycle.

For continuity of service, it has been customary to build double-circuit lines. However, even with 2 circuits a large proportion of the faults may involve both circuits, because when lightning current passes down a tower, the tower potential may be raised above that of all 6 conductors, and the probability is that more than one conductor will flash over at a time. On wood-pole lines, faults frequently spread between circuits because of the high resistance of the pole, which does not relieve the potential due to a direct stroke.

For the foregoing reason some power companies now are building single-circuit lines equipped with expulsion protective gaps, instead of double-circuit lines. Among these may be mentioned the Pennsylvania Power and Light Company's 66-kv wood-pole lines, the Carolina Power and Light Company's 115-kv wood-pole lines, and the American Gas and Electric Company's 132-kv steel-tower lines. In the limited time they have been in operation, such lines have had very good service records.

Expulsion protective gaps were placed on one circuit of the Glenlyn-Roanoke double-circuit line in 1933, and on the Roanoke-Danville single-circuit line in 1934. In the 3 years, 1933, 1934, and 1935, a total of 339 gap operations occurred, with 30 cases of incorrect operation. The outages on the 2 circuits of the Glenlyn-Roanoke line averaged 10 per year during the 3 years of expulsion-gap operation, against an average of 18 per year during the previous 7 years. On the Roanoke-Danville line the outages for the 2 years of gap operation averaged 4.5 per year against an average of 19.5 per year for the 7 previous years.

The Pennsylvania Power and Light Company and the Pennsylvania Water and Power Company installed, in 1935, expulsion protective gaps and Deion gaps on about 98 miles of 66-kv line, consisting of 81 miles of single-circuit wood H-frame line and 17 miles of double-circuit steel-tower line. Out of a total of 944 structures, 543 were equipped with gaps. During the 1935 season there were 374 tube operations, with 8 tube flashovers or failures. There were 18 tripouts on these lines during this period.

Data given for the lines of the Appalachian Electric Power Company indicate that for the Glenlyn-Roanoke line the outages on the double-circuit were reduced about 45 per cent after the installation of expulsion protective gaps on one circuit. On the Roanoke-Danville single-circuit line the outages were reduced about 75 per cent after the installation of the expulsion protective gaps. Approximately 9 per cent of the gap operations on both lines were incorrect.

Data at hand for the 66-kv Pennsylvania lines do not permit of an evaluation of the improvement in operation due to the gaps, except perhaps in case of 2 of the lines. On these 2 lines gaps were installed to guyed structures only, which comprise about 25 per cent of the structures on the Northumberland-Williamsport line and about 14 per cent on the Berwick-Bloomsburg line. The operating record of these lines showed 1 tripout on each line in 1935 as compared with a yearly average of 7 tripouts on the Northumberland-Williamsport line and 5 on the Berwick-Bloomsburg line during the previous 4 years. There were many correct gap operations (the incorrect gap operations were slightly over 2 per cent on these lines).

It cannot be said that each correct gap operation saves a tripout. It must be remembered that the flashover potential of the expulsion-gap assembly is considerably less than that of the insulation assembly which it is designed to protect (10 to 15 per cent less for the 132-kv steel-tower lines and about 40 per cent less for the 66-kv wood-pole lines considered in this discussion). It is obvious therefore that the number of expulsion-gap operations will be greater than the number of insulator flashovers that would have occurred if the gaps had not been installed. Nevertheless, it is probably true that the

gaps saved a large number of tripouts on these lines during the period of their operation.

Petersen Coils

Briefly, the Petersen coil is a reactance coil connected between the system neutral and ground and specially proportioned in relation to the capacitance of the system. Upon the occurrence of a line-to-ground fault on one conductor, a lagging current will flow through the coil which is equal in magnitude and opposite in phase to the charging current at the fault. Under this condition the resultant current at the fault becomes zero and the fault is cleared.

In some instances there is a residual in-phase component of current at the fault, which cannot be neutralized by the Petersen coil. This current is due to corona on the line conductors, leakage over insulators, and other factors. If large enough to be important, the in-phase component may be neutralized by special auxiliary means. It is obvious that the Petersen coil cannot neutralize a line-to-line fault.

The use of the Petersen coil in Germany and other European countries has been very extensive. Approximately 1,000 coils have been installed on systems varying in voltage from 5 to 220 kv. In the United States the solidly grounded neutral system has been very popular, and therefore Petersen coils and other grounding devices have not received wide acceptance.

At the present time there are 5 coils in operation in the United States as follows: an 800-kva continuous-rated coil on the 44-kv system of the Georgia Power Company; 2 10,000-kva 10-minute-rated coils on the 140-kv system of the Consumers Power Company, Mich.; a 3,000-kva 30-minute-rated coil on the 33-kv system of the Central Maine Power Company; and a coil rated 800 kva for 30 minutes on the 33-kv system of the Public Service Company of Indiana. A 10,000-kva 10-minute coil will be installed during the spring of 1937 on the 100-kv system of the Public Service Company of Colorado.

The first Petersen coil in the country was an 800-kva continuous-rated coil installed on the Lock 12-Vida-Selma-Montgomery section of the Alabama Power Company's 44-kv system in 1921. This coil operated successfully until early in 1924 when it was removed because the system mileage had practically doubled and greatly outgrown the capacity of the coil. The coil was moved to the Georgia Power Company's system and installed on the 130-mile Marietta section of the 44-kv system, where it has been in successful operation for about 6 years.

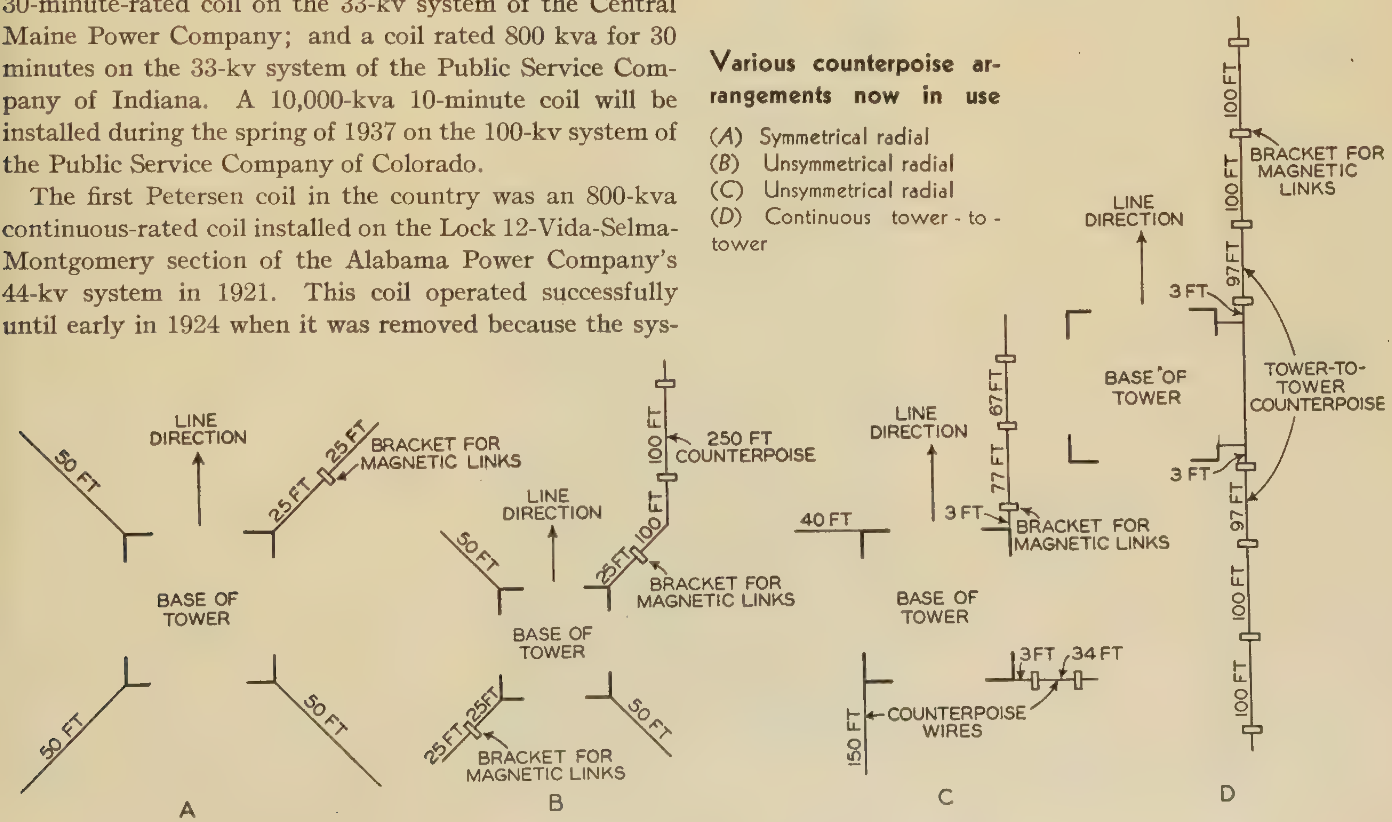
The Consumers Power Company's coils were installed late in 1931. The system consists of 275 miles of line on steel towers, all but about 40 miles of which is single circuit. There are no overhead ground wires on this line. The coils are rated 10,000 kva for 10 minutes and are installed one at Saginaw and one at Alcona. Operation on this system shows approximately 70 per cent of all faults in about 5 years' service cleared without oil circuit-breaker operation.

The Central Maine system consists of 560 miles of 33-kv line on wood poles with pin insulators and no overhead ground wires. The Petersen coil was installed in the fall of 1935. In the 14 months from August 1, 1935 to October 1, 1936 the Maine coil operated 54 times and cleared all faults that were not permanent, without a service interruption. In the Gulf Island Station in the 6 years before the coil was installed, there were 27 insulator or bushing flashovers associated with faults at other points on the system. Since the coil has been in service flashovers of this type have not occurred.

It is probable that the majority of faults start as single-phase-to-ground disturbances and that later other phases may become involved. It is also probable that high tower-footing resistance, by allowing the tower potential to rise above that of the conductors, is responsible for the other phases becoming involved. Consequently, a reduction in tower-footing resistance will decrease the number of phase-to-phase faults, and allow the single-phase faults to be cleared by Petersen-coil operation.

Various counterpoise arrangements now in use

(*A*) Symmetrical radial
(*B*) Unsymmetrical radial
(*C*) Unsymmetrical radial
(*D*) Continuous tower-to-tower



Immediate Initial Reclosure

During the last few years an operating procedure has been developed to improve continuity of service on feeders and tie lines: The practice of immediate initial reclosure of a circuit-breaker that has been tripped automatically. Many of the causes of short circuits have disappeared by the time the controlling breaker can be reclosed. Experience has demonstrated that immediately returning voltage to a circuit not only does no harm, but completely neutralizes the effects of interruption on most types of load.

All motors connected to an immediately reclosed circuit must have time delay on their undervoltage releases, if full benefit is to be derived from this procedure. Otherwise the motors having an instantaneous under-voltage device will be disconnected during the period of no voltage, and it then makes no difference whether the voltage is re-established immediately or later. Provided under-voltage devices, when used, have time-delay features, it is possible to open the circuit-breaker and immediately reclose it with no detrimental effect on many kinds of load. The value of this procedure increases with the prevalence of lightning on a system, for then a smaller proportion of faults arises from causes that are permanent.

Some companies, especially in the Southeast, have applied immediate reclosure to their systems with significant improvement in their service. On one system it has been found that a circuit can be returned immediately to service after nearly 90 per cent of the tripouts, and remain closed with no loss of load and no detriment to service.

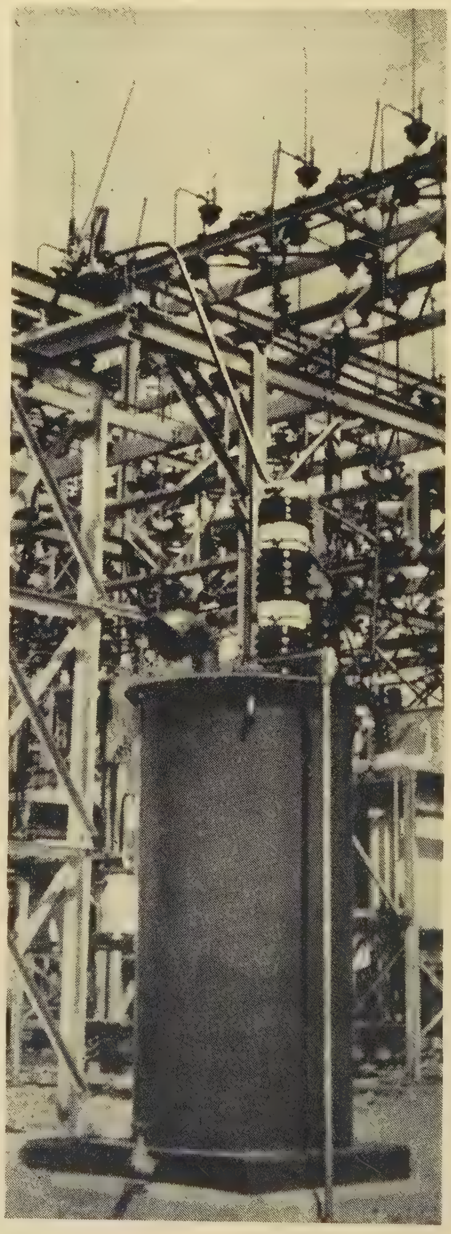
Immediate reclosure does not benefit all types of loads. Where it is applicable, and where many of the outages result from transitory causes, such as lightning, immediate reclosure is usually a simple, inexpensive, and very effective means of improving the service. In addition, immediate reclosure reduces service interruptions from certain causes from which the other protective means may not. These include temporary conductor contact from wind, sleet, or foreign materials on the line, such as kite strings, tree branches, and birds, which often leave the line clear after the first tripout.

Summary

None of the means of lightning protection considered here has shown a perfect record. In some instances, however, overhead ground wires, when properly installed to shield the conductors from direct strokes and when accompanied by adequate insulation and low tower-footing resistance, have shown an almost perfect record.

The expulsion protective gap has shown good performance, especially on wood-pole H-frame lines. Improvements in the tubes may be expected as a result of past operating experience. This will tend further to improve the performance of these gaps. There is some evidence that equipping one circuit of a double-circuit line is beneficial, and on the Pennsylvania systems equipping only the guyed structures was apparently beneficial.

In the limited experience with Petersen coils in the United States, this equipment has shown a record of suppression of faults of the order of 70 to 80 per cent. Low tower footing resistance is of importance here in limiting the number of phase-to-phase flashovers, thus giving the Petersen coil full opportunity of taking care of the line-to-ground flashovers for which it is adapted.



Petersen coil installed on a 33-kv system

Immediate initial reclosure has been applied mainly to radial feeders and tie lines of medium voltages (up to 66 kv), although trial installations have been made on higher-voltage lines (up to 132 kv). A certain amount of maintenance is involved in the oil circuit-breakers, relays, and other equipment.

It is difficult to evaluate in general terms the cost of applying the various methods mentioned, so that the following figures should be considered as only very rough: For a 115- or 138-kv double-circuit steel-tower line, the cost of 2 overhead ground wires plus a continuous tower-to-tower counterpoise wire would be roughly \$1,500 or \$1,600 per mile. The cost of expulsion protective gaps plus installation would be roughly \$1,200 to \$1,400 per mile for both circuits or \$600 to \$700 if only one circuit is equipped. The cost of a Petersen coil for a 100-mile line plus installation would be roughly \$10,000, or \$100 per mile. Immediate initial reclosure is probably the least expensive of any of the methods mentioned, assuming that suitable breakers and relays are already available and that only the automatic reclosing device is required.

Each method has its advantages and disadvantages, and the best method for a particular case can be selected only after a study of all the circumstances.

Further Characteristics of the Carbon Arc

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In this paper the carbon arc is considered in its 3 characteristic forms, the low intensity arc, the high intensity arc, and the flame arc. The influence of arc current on the energy emission is discussed in relation to each of the 3 types, as well as the effects of variation in arc voltage.

The discussion covers characteristics which should be given consideration in order to make most effective application of the various types of arcs.

IN THE course of a previous paper, which discussed the general characteristics of the carbon arc, it was pointed out that there are 3 distinct types of carbon arcs, the low-intensity neutral-core arc, the flame arc, and the high-intensity arc. The characteristic features distinguishing these 3 types of arcs were also described. Each of these types has its own peculiar characteristics and is affected in different manner or degree by variations in arc conditions. It is the purpose of the present paper to present further data on the characteristics of these arcs and to consider the effect of certain variables on the character and intensity of the light emitted.

Distribution of Radiant Energy

The quality of light from the high-intensity arc is inherently whiter than that from the low-intensity neutral-core arc. This might be anticipated from the much higher intrinsic brilliancy of the crater. Spectral energy distribution curves for all carbon arcs show 2 characteristic peaks, one of moderate intensity at about 2,500 Angstrom units and a dominant band of emission, commonly called the "cyanogen peak," at about 3,800-3,900 Angstrom units. Except for the influence of this cyanogen peak, the energy emission from the d-c low-intensity neutral-core arc at full brilliancy tends to follow the theoretical black-body radiation curve for 3,810 degrees Kelvin, the brightness temperature of carbon at the point of vaporization. The emission from the d-c high-intensity arc, on the other hand, comes nearer to the black-body curve for 5,600 degrees Kelvin. This difference is illustrated in figure 1, in which all curves have been adjusted to a maximum value of 100 (exclusive of cyanogen peak) on an arbitrary scale of intensity. It is obvious from the energy distribution shown by these curves that the light from the high-intensity arc has a substantially even balance of all colors and comes close to our conception of a pure white light. It is equally obvious that the light from the low-intensity arc has a yellowish tint resulting from the higher intensity of the longer wave lengths within the visible range.

The distribution of radiant energy from the flame arc is dependent largely on the composition of the core. This is illustrated, for the visible range, by figure 2 where the output from a 30-ampere 50-volt a-c arc between neutral-core carbons is compared with that from carbons burned under the same conditions and having identical outer shells but whose cores contain, respectively, cerium, calcium, and strontium. Figure 3 shows the effect of variation in core composition on the ultraviolet emission. The respective core compositions in this case contain the elements listed below the curves. Many elements, other than those whose effects are illustrated in figures 2 and 3, have pronounced influence on the quality of emission in both the ultraviolet and the visible portions of the spectrum. This fact makes the flame arc a highly flexible source of radiation, capable of adaptation to a wide range of requirements in radiation characteristics.

Effects of Increasing Arc Current

In all types of arcs, one effect of increasing arc current is to increase the light output. This result, however, is subject to certain practical limitations characteristic of the various types. For a given type and size of trim there is a certain range of current within which best results are obtained. Operation at lower currents allows the arc to wander over the face of the carbon with resulting unsteadiness of light. Currents above this optimum range likewise produce an unsteady arc due to the effects of overloading the carbons. Carbon manufacturers have carefully determined the optimum range of current for the several types and sizes of carbons, and their instructions should be followed. As long as proper arc conditions are maintained, operation within the recommended range of current can be depended on to produce satisfactory arc performance.

In the d-c low-intensity arc the light produced is largely dependent on the area and intrinsic brilliancy of the positive crater. Only a small percentage of the total light comes from the arc stream and the less brilliant tip of the negative carbon. Mott and Kunzmann (reference 2) have shown that the relation between arc current and crater area may be expressed by an equation of the form

$$A = 7 + 0.47 I^e$$

where

A = crater area in square millimeters
I = arc current in amperes
e = 1.4 for carbons of large diameter
= 1.35 for carbons of small diameter

More recent observations (reference 3) on positive carbons of 10 to 13 millimeters diameter, designed for use in low-intensity d-c projection lamps of the reflecting type,

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Table I—Influence of Arc Current on Low-Intensity D-C Arc at 55 Volts, SRA Trim

Diameter Positive Carbon, Milli-meters	Arc Current, Amperes	Crater Area Square Milli-meters	Maximum Intrinsic Brilliancy, Candle Power per Square Milli-meter	Candle Power Di-rectly in Front of Crater	Candle Power per Arc Watt
10	21	34.8	174	5,720	4.95
10	24	39.2	175	6,650	5.04
12	28	49.0	171	7,900	5.12
12	34	60.0	175	9,800	5.24
13	32	61.0	171	9,100	5.16
13	44	77.9	172	13,200	5.45

Table II—Influence of Arc Current on High-Intensity D-C Arc With Rotating Positive

Diameter of Positive Carbon, Milli-meters	Arc Current, Amperes	Average Arc Voltage	Crater Area, Square Milli-meters	Intrinsic Brilliancy, Candle Power per Square Milli-meter	Candle Power of Crater Light	Candle Power per Arc Watt
9	50	44	29.3	430	12,500	5.68
9	75	54	35.4	705	25,000	6.17
11	90	60	56.0	750	42,000	7.78
13.6	100	63	73.3	535	39,000	6.20
13.6	125	68	92.0	815	75,000	8.82
16	135	70	132.0	570	75,000	7.94
16	155	72	145.7	695	101,000	9.05

support the substantial accuracy of this formula. The measured values of crater area represent values of e ranging from 1.32 to 1.35.

The vaporizing temperature of carbon having been approached in the low-intensity arc, further increase in arc current results in little increase in intrinsic brilliancy of the positive crater. The increase in crater area, however, does result in an increase of total light emission. The optical systems used in most projection lamps and projectors place limitations on the area of the positive crater face from which the light can be effectively focused within the dimensions of the aperture plate and projected onto the screen. For this reason, when a projector carbon has been raised to its maximum intrinsic brilliancy, further increase in current produces little, if any, increase in screen illumination. Table I shows the influence of arc current on the crater characteristics and light output of the d-c low-intensity arc with the type of carbons now extensively used in reflecting type projection lamps.

Mott and Kunzmann (2) found that the candle power of low-intensity searchlight carbons, within the range of 20 to 150 amperes, followed substantially the curve expressed by the equation,

$$CP = 51.4\, I^{1.4}$$

The carbons now used in the d-c low-intensity reflector arc show higher efficiency in light production. The candle power measurements given in table I are closely approximated by the equation $CP = 164.0\, I^{1.165}$.

In the d-c high-intensity arc, increase of current increases both the area and the depth of the positive crater. The increase in crater area with increasing current is shown by the curves in figure 4. It is apparent from these curves that, at the same current, 2 carbons of different diameters will show a substantially larger crater on the larger carbon. The influence of arc current on the intrinsic brilliancy of the positive crater is shown by the curves in figure 5. Here it is apparent that, of 2 carbons of different diameters operated at the same current, the

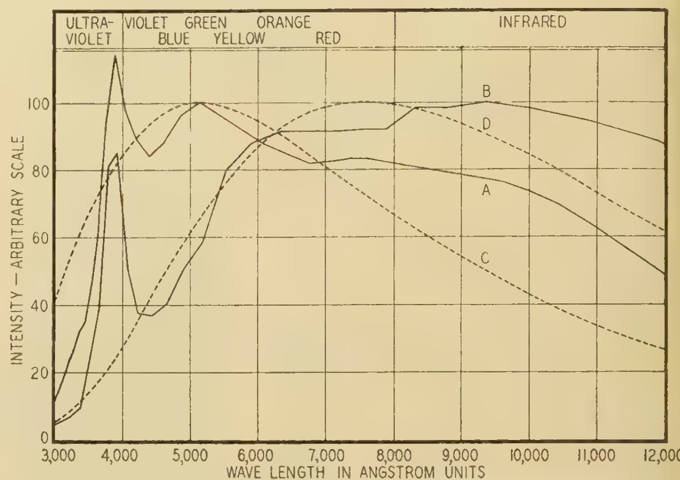


Fig. 1. Spectral energy distribution curves

A—13.6-millimeter d-c high-intensity arc, 125 amperes, 63 volts
B—12-millimeter d-c low-intensity arc, 30 amperes, 55 volts
C—Theoretical black-body radiation at 5,600 degrees Kelvin
D—Theoretical black-body radiation at 3,810 degrees Kelvin

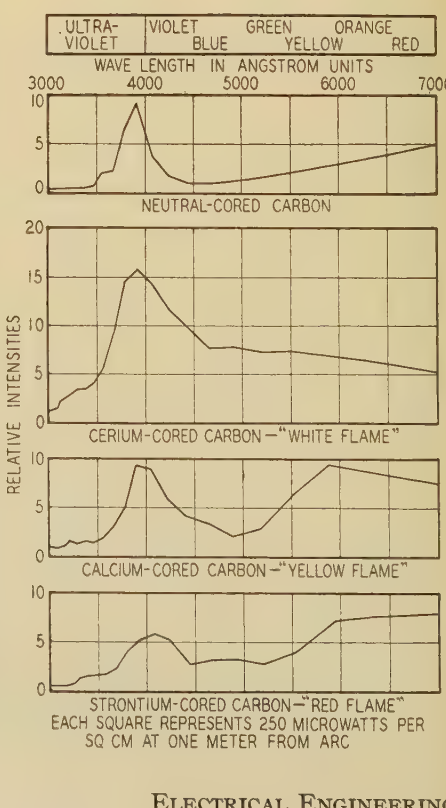


Fig. 2. Effects of core composition on near ultraviolet and visible radiation—30 amperes, 50 volts, a-c

smaller will have the higher intrinsic brilliancy. This is the natural result of concentrating the energy of the arc within a smaller area. It is evident, from a comparison of these curves with the data given in table I, that much higher intrinsic brilliancies are available from the high-intensity arc than are possible to obtain from the low-intensity arc.

Table II shows the effect of arc current on the crater light from the d-c high-intensity arc with rotating positive electrode and also shows the arc-voltage representative of average operating conditions at the specified arc currents. The figures in this table do not include the light from the tail flame of the arc, which represents about 32 per cent of the total light output but cannot be properly

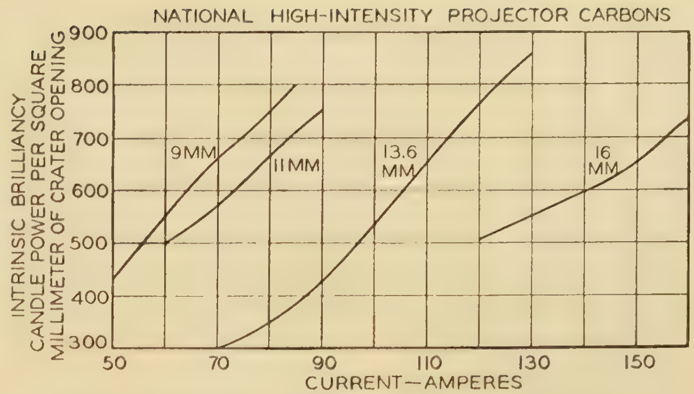


Fig. 5. Intrinsic brilliancy versus arc current—d-c high-intensity arc

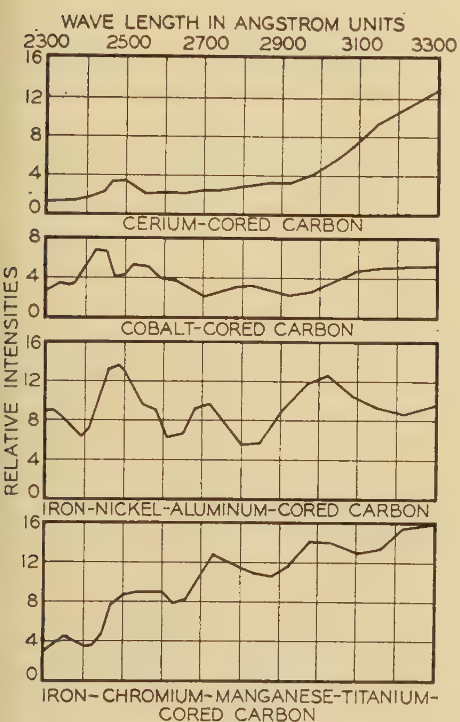


Fig. 3. Effects of core composition on short ultraviolet radiation—60 amperes, 50 volts, a-c

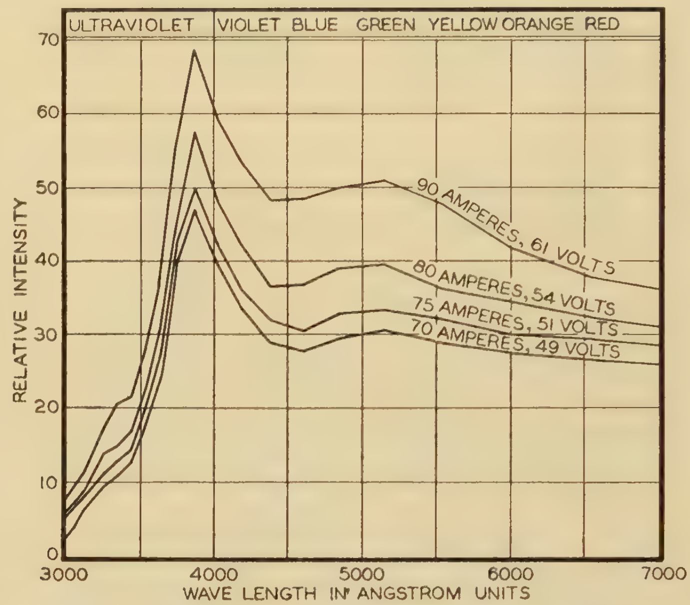


Fig. 6. Effect of arc current on energy distribution d-c high-intensity arc—9-millimeter positive

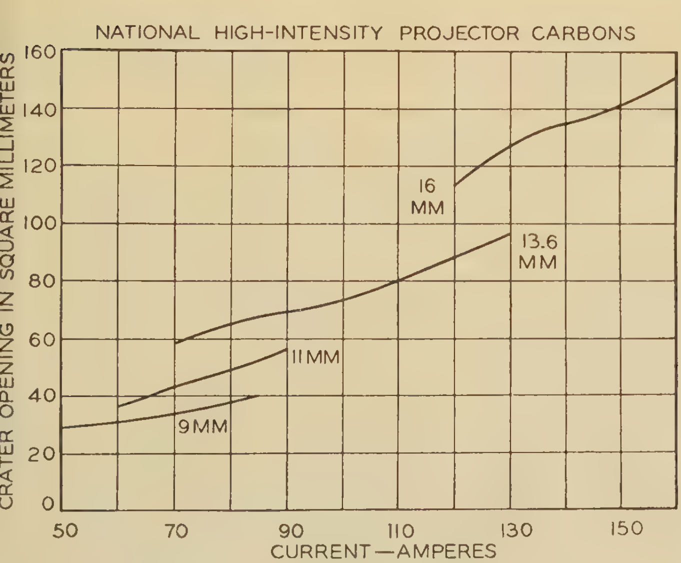


Fig. 4. Crater area versus arc current—d-c high-intensity arc

focused by the optical system of projection lamps and therefore does not add to the screen illumination.

Increasing current does not greatly affect the quality of light emitted by the high-intensity arc. This is shown in figure 6 by the energy-distribution curves for a high-intensity arc with 9-millimeter positive operated in a reflecting type projection lamp at arc currents of 70, 75, 80, and 90 amperes. Over this range of current the increase in arc watts and the increase in radiant energy are in approximately the same ratio, the effect of increasing current being slightly more pronounced in the blue and green bands of the spectrum than in other portions.

With flame arcs the effects of increasing arc current are decidedly complex. They vary with the composition of the flame supporting core, with the range of current in which comparison is made and with the portion of the spectrum in which intensity of radiation is observed. A few examples are cited to illustrate the effects of arc current under specific conditions.

The increase in intensity of ultraviolet radiation, between the limits of 2,900–3,100 Angstrom units, which

results from increasing arc current, with voltage constant, is shown by the curves in figure 7. The upper curve shows the effect on a carbon having iron, nickel, and aluminum in the core and the lower curve the effect on one containing cerium. The curves in figure 8 show the corresponding effects on total radiation over a broad band of the spectrum, from 1,700 to 6,500 Angstrom units. This includes practically all ultraviolet emission from the arc and a major portion of the visible light. In this case, the upper curve represents the cerium-cored carbon and the lower curve the carbon containing iron, nickel, and aluminum.

The effect of current increase at different wave lengths can be illustrated by curves showing the variation in mean exponential relation between changes in arc current and resulting changes in intensity of radiation. These curves, presented in figure 9, are based on the equation

$$\frac{W_2}{W_1} = \left(\frac{I_2}{I_1}\right)^e$$

where

W = intensity of radiant energy
I = arc current in amperes
e = exponential relation between current and intensity

Curves are drawn for 2 ranges of arc current, 30–60 and 60–90 amperes, and for the 2 types of carbons shown in figures 7 and 8. The complexity of the relationship between arc current and resulting energy emission at different wave lengths is evident from these curves.

A series of observations of more practical application, relating to the light output of the flame arc under varied conditions of operation is given in table III. These observations were made with white flame (cerium cored) photographic carbons in the lamp mechanism of a photoengraving lamp of standard make.

The data in table III disclose that, under the same conditions of arc voltage and current, the d-c arc between flame carbons gives higher light output than the a-c arc; the d-c arc with upper carbon positive gives higher light output than with upper carbon negative; and, the d-c arc with cerium-cored negative gives higher light output than with neutral-cored negative.

While the foregoing figures show a decided advantage for the d-c arc over the a-c arc on the basis of candle power per arc watt, this advantage is more than offset when the comparison is made on a basis of candle power per line watt between a single d-c arc on a 115-volt circuit and a transformer-operated a-c arc. It is common practice, however, particularly in twin-arc lamps, to operate 2 d-c arcs in series from the standard-voltage d-c circuit at a somewhat lower arc voltage than that used in obtaining the data given in table III. Under these conditions comparison on the basis of candle power per line watt favors the d-c arc when no reflectors are used. This was the condition under which data was obtained for the comparison given in table IV.

The use of reflectors may and, in most designs, does more than offset the primary advantage of the d-c twin arc over the single, transformer-operated a-c arc. This is because higher efficiency in reflector design is possible with the single arc which can be centered in a reflector of symmetrical form.

Effects of Arc Voltage

The d-c low-intensity arc with neutral-cored carbons gives optimum performance over a rather limited range of arc length and arc voltage. For this reason it is customary to maintain approximately constant arc voltage and to vary the light output by adjustment of arc current. The d-c low-intensity reflecting arc is usually operated with 54–57 volts at arc. Curve *A* in figure 10 is representative of the average relationship between arc voltage and current in other types of lamps using the d-c low-intensity arc.

The d-c high-intensity arc, under given conditions of trim and arc current, should also be operated at essentially constant arc voltage. In fact, arc voltage is often used as the control factor for operating the carbon-feeding

Table III—Light Output of Cerium-Cored Flame Arc at 55 Volts

Upper Carbon	Lower Carbon	Power	Arc Current, Amperes	Mean Spherical Candle Power	Mean Spherical Candle Power per Arc Watt
1/2- by 12-inch cerium cored	1/2- by 12-inch cerium cored	A-C	30	6,985	4.23
5/8- by 12-inch cerium cored	1/2- by 12-inch cerium cored	A-C	45	9,800	3.96
5/8- by 12-inch copper coated, cerium cored	5/8- by 12-inch copper coated, cerium cored	A-C	60	13,500	4.09
Upper Carbon Positive	**Lower Carbon Negative**				
1/2- by 12-inch cerium cored	1/2- by 12-inch cerium cored	D-C	30	10,110	6.13
5/8- by 12-inch cerium cored	1/2- by 12-inch cerium cored	D-C	45	13,520	5.46
5/8- by 12-inch copper coated, cerium cored	5/8- by 12-inch copper coated, cerium cored	D-C	60	21,120	6.40
Upper Carbon Negative	**Lower Carbon Positive**				
1/2- by 12-inch cerium cored	1/2- by 12-inch cerium cored	D-C	30	7,540	4.57
5/8- by 12-inch cerium cored	1/2- by 12-inch cerium cored	D-C	45	11,840	4.78
5/8- by 12-inch copper coated, cerium cored	5/8- by 12-inch copper coated, cerium cored	D-C	60	15,970	4.84
1/2- by 12-inch neutral cored	1/2- by 12-inch cerium cored	D-C	30	6,985	4.23
5/8- by 12-inch neutral cored	1/2- by 12-inch cerium cored	D-C	45	8,710	3.52
5/8- by 12-inch copper coated, neutral cored	5/8- by 12-inch copper coated	D-C	60	11,410	3.46

nechanism. Nevertheless, arc voltage alone does not fford a sufficient basis for adjustment of the carbons in he high-intensity arc. Joy and Downes (reference 4) ave published the results of a thorough investigation of his subject. They have shown that it is possible to perate a high-intensity arc at 120 amperes with 70 volts rop across the arc at arc lengths ranging from $^5/_8$ inch o $1^1/_8$ inches. However, widely divergent results as to teadiness and quantity of crater light are encountered ver this range of arc lengths. Relative position of ositive and negative carbons is probably a factor of reater importance than arc voltage in maintaining

able IV—Comparison Between D-C Twin-Arc and ransformer-Operated A-C Arc; All Carbons Cerium Cored

	2 45-Volt, D-C Arcs in Series on 115-Volt Line, Upper Positive		55-Volt A-C Arc, Transformer Operated; 3 Per Cent Loss Allowance	
Arc Current, Amperes	Mean Spherical Candle Power	Mean Spherical Candle Power per Line Watt	Mean Spherical Candle Power	Mean Spherical Candle Power per Line Watt
30	16,540	4.80	6,985	4.10
45	22,140	4.28	9,800	3.84
60	34,600	5.01	13,500	3.97

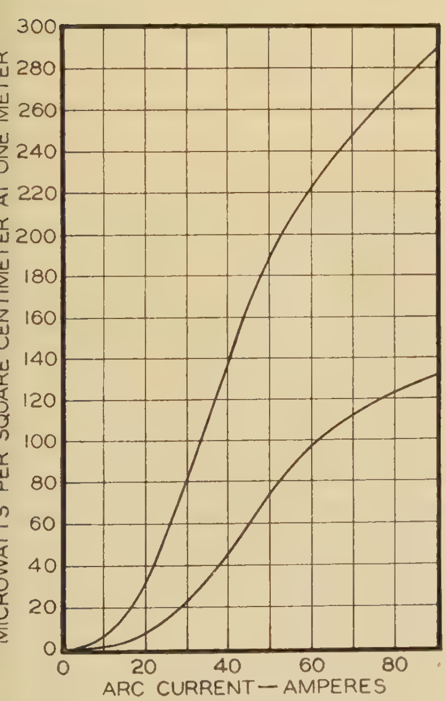


Fig. 7. Variation of ultraviolet (2,900–3,100 Angstrom units) with current-flame arc at 50 volts, a-c

Upper curve—Iron-nickel - aluminum core

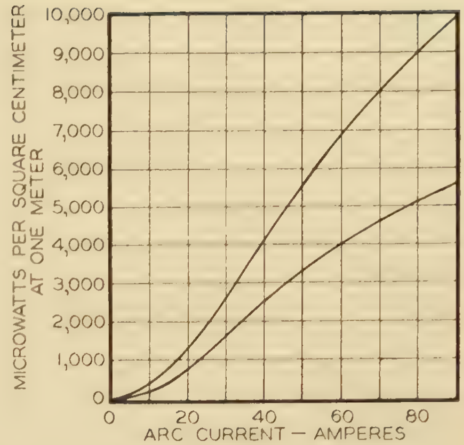
Lower curve—Cerium core

orrect arc conditions. Without discussing theories of he action taking place within the crater of the high ntensity arc, it will here suffice to say that steady burning, niform light output and characteristic extreme brilliancy are dependent on the maintenance of uniform rater depth and form and uniform conditions within the rater. It is obvious that these factors will be influenced

Fig. 8. Variation of radiation, from 1,700 to 6,500 Angstrom units, with current flame arc at 50 volts, a-c

Upper curve—Cerium core

Lower curve—Iron-nickel - aluminum core



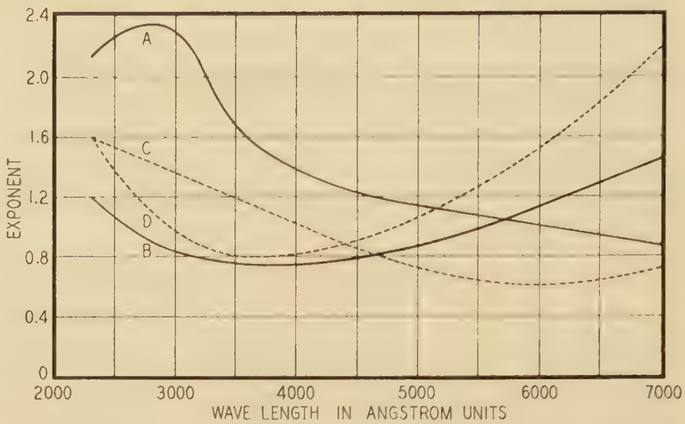


Fig. 9. Mean exponential relation between arc current and energy emission at different wave lengths; 50 volts, a-c

A—Cerium-cored carbon; 30–60-ampere range
B—Cerium-cored carbon; 60–90-ampere range
C—Iron-nickel-aluminum-cored carbon; 30–60-ampere range
D—Iron-nickel-aluminum-cored carbon; 60–90-ampere range

to a marked degree by the manner in which the negative arc stream impinges on the positive crater. Detailed instructions for obtaining optimum performance are contained in a handbook which has been made available to projectionists and other users of high-intensity arcs. Values representing average arc voltage for the d-c high-intensity arc with rotating positive, under correct operating conditions, are indicated by curve *B* in figure 10.

There has recently come into extensive use in motion picture projection a carbon arc which our present knowledge indicates to be a true high-intensity arc but which is operated at much lower arc voltage than the older types of high-intensity arcs. This arc is known in the motion picture industry as the Suprex type arc. Among several points of difference from the older types is the fact that it is operated at a relatively short arc length with a drop of 31 to 40 volts across the arc. Due to this low arc voltage, it is desirable that the Suprex arc should be operated from a low-voltage source of power. This is necessary to obtain best performance as well as good power economy.

It has been demonstrated that the crater depth of the high-intensity positive increases with increase of arc current; that the voltage drop in the arc stream is com-

paratively low and does not materially increase with increased current; and, on the other hand, that the voltage drop within the positive crater is comparatively high and does increase materially as current and crater depth increase (reference 5). When some disturbance to the "high intensity effect" takes place, crater form, depth and voltage are affected, as well as light output. Normal crater conditions and light output are re-established by the increase in current resulting from the drop in arc voltage and the time required to restore normal conditions depends on the amount of current increase. When this low-voltage arc is operated with heavy ballast on a 115-volt power circuit, so much of the total energy is consumed in the ballast that relatively large changes of arc voltage produce only slight changes in arc current. It therefore takes considerable time for restoration of normal crater conditions to be effected. On the other hand, when the voltage of the power source is not greatly above that of the arc, and the ballast correspondingly small, much larger fluctuations in arc current occur in response to a disturbing influence so that normal crater conditions and light output are restored more quickly.

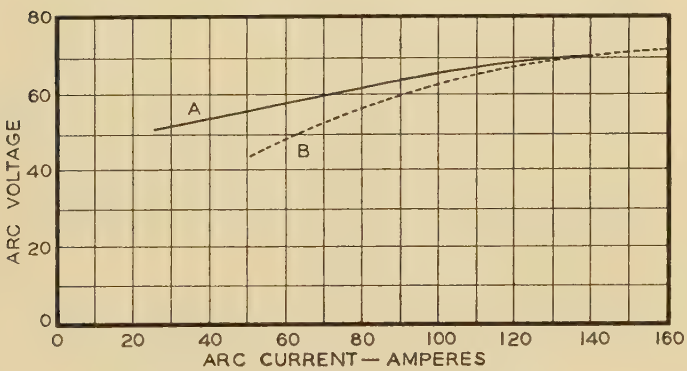


Fig. 10. Arc voltage versus arc current

A—D-c low-intensity arc
B—D-c high-intensity arc

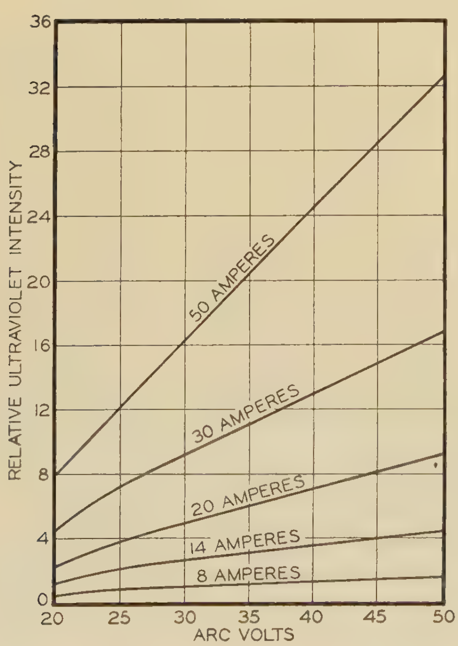


Fig. 11. Ultraviolet output (2,900 – 3,100 Angstrom units) versus arc voltage; iron - nickel - aluminum core

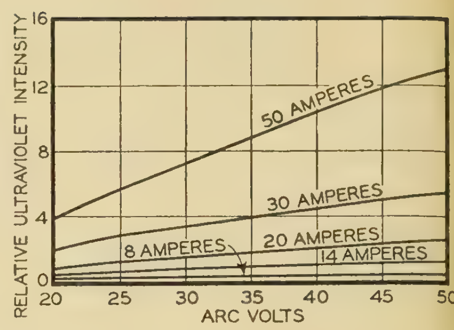


Fig. 12. Ultraviolet output (2,900–3,100 Angstrom units) versus arc voltage; cerium core

The operator of a Suprex type of arc, using a low-voltage power source, should therefore expect to see wider fluctuations of current than are customary with other types of arcs. Furthermore, it should be recognized that fluctuation of current is not necessarily associated with corresponding fluctuation of light but is, rather, a stabilizing factor by means of which uniform light output is maintained.

The flame arc can be operated satisfactorily over a considerable range of arc voltage although, under certain conditions or in some particular lamp, best results may be obtained over a relatively narrow voltage range. The effect of changes in arc voltage on ultraviolet output from 2,900 to 3,100 Angstrom units is shown by the curves in figures 11 and 12. The former is for a carbon containing iron, nickel, and aluminum in the core and the latter for a cerium-cored carbon. Relative effect of changes in arc current and in arc voltage can be observed by comparing these curves with those in figure 7.

Conclusion

The carbon arc is firmly established as a powerful, efficient, and highly flexible source of radiation, possessing certain advantageous characteristics which make it a most useful source of radiant energy for many purposes. It is true of the carbon arc, as it is of all types of light sources, that effective application requires consideration of the inherent characteristics of the source and adaptation of operating conditions to these characteristics. Each type of arc has its own peculiar advantages and fields of application. The foregoing discussion covers some of the features of the various types of arcs to which attention should be given in making the initial application as well as in subsequent operation.

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Current Loci in the General Linear A-C Network

By ALAN HAZELTINE
FELLOW AIEE

OUR PROBLEM is to find the way in which the currents and voltages vary in a general linear a-c network connected to a single adjustable branch, hen the current of that branch is adjusted under some ven restriction. In a general linear network, each anch has a fixed impedance; and the impressed voltages ıd currents (of which there may be any number, but sually is only one) are also fixed.* The impressed oltages and currents are supposed sinusoidal and of the me frequency; and we are concerned only with the eady state. So all voltages and currents are sinusoidal ıd may be represented analytically by complex numbers ıd graphically by plane vectors.

If we write for the network a complete set of circuit uations, these will be linear in the unknown voltages ıd currents, together with the current I_L of the adjust- ole branch. If we are interested in a certain current I_M, e may eliminate all other unknown currents and voltages ccessively in the usual way, by multiplying the equa- ons by suitable constants and adding them. At each ep the resulting equations then remain linear; and we all finally arrive at a linear equation connecting only $_M$ and I_L:

$$_M = I_{M0} + K_M I_L \qquad (I_{M0}, K_M \text{ are constants}) \tag{1}$$

vidently I_{M0} is the value of I_M when $I_L = 0$ and is due the impressed voltages and currents. While K_M is e value of I_M when $I_L = 1$ and all impressed voltages ıd currents are removed (making $I_{M0} = 0$): here the ıit current I_L must be supplied from a source in its anch; and the impressed voltages must be removed by ort-circuiting them, the impressed currents by opening eir circuits, so as not to alter the impedances of the twork.

If we had been interested in a voltage E_M, instead of a ırrent I_M, a similar equation would have been found:

$$_M = E_{M0} + z_M I_L \qquad (E_{M0}, z_M \text{ are constants}) \tag{2}$$

vidently E_{M0} is the value of E_M when $I_L = 0$; and z_M the value of E_M when $I_L = 1$ and the impressed voltages ıd currents are removed. In particular, we have for e voltage E_L across the adjustable branch

$$_L = E_{L0} - z_S I_L \qquad (E_{L0}, z_S \text{ are constants}) \tag{3}$$

ere E_{L0} is the value of E_L when $I_L = 0$ (i.e., the *open- rcuit voltage* of the adjustable branch) and is due to the ıpressed voltages and currents of the network. While is the value of E_L when $I_L = -1$ and the impressed voltages and currents are removed. If we restrict our- selves (as we shall) to an adjustable branch connected to the network *only through 2 terminals* (in particular, having no mutual inductance to the network), then z_S is the impedance *looking into the network* between these ter- minals, since $-I_L = 1$ represents the current sent *into* the network by the voltage E_L due to a source in the adjustable branch.†

In place of an *open-circuit* calculation to determine I_{M0} (or E_{M0}) and E_{L0}, or in place of an *impedance* calcu- lation to determine K_M (or z_M) and z_S, we may use a *short-circuit* calculation, in which the adjustable branch is short-circuited, making $E_L = 0$. If I_M, E_M, and I_L under this condition are denoted by I_{MS}, E_{MS}, and I_{LS}, equa- tions 1, 2, and 3 give

$$\left.\begin{aligned} I_{MS} &= I_{M0} + K_M I_{LS} \\ E_{MS} &= E_{M0} + z_M I_{LS} \\ 0 &= E_{L0} - z_S I_{LS} \end{aligned}\right\}, \text{ whence } \left\{\begin{aligned} I_{M0} &= I_{MS} - K_M I_{LS} \\ E_{M0} &= E_{MS} - z_M I_{LS} \\ E_{L0} &= z_S I_{LS} \end{aligned}\right\} \text{ or}$$

$$\left.\begin{aligned} K_M &= \frac{I_{MS} - I_{M0}}{I_{LS}} \\ z_M &= \frac{E_{MS} - E_{M0}}{I_{LS}} \\ z_S &= \frac{E_{L0}}{I_{LS}} \end{aligned}\right\} \tag{4}$$

If not restricted, the current I_L would be represented by a vector whose extremity could lie anywhere in its plane. When, however, I_L is restricted by a single real equation, the extremity of its vector will in general lie on a curve, called the *locus* of I_L for this restriction. For example, if the restriction is that the apparent power of the variable branch be constant, $E_L I_L = A_L$, the locus of I_L will be one of those shown in figure 1*a*, according to the value of A_L.** Now multiplying I_L by the complex constant K_M will change its magnitude in a fixed ratio and its phase by a fixed angle; so the loci of $K_M I_L$ will be similar to those for I_L and similarly related to one another, but will in general be changed in scale and rotated, as represented in figure 1*b*, with O' as the origin. Then adding the complex constant I_{M0}, to give I_M according to equation 1, merely shifts the origin to a new point O, figure 1*b*. That is, *every variable current* I_M (*and every variable voltage* E_M) *of the network will have loci similar to those of* I_L.

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* Ve do not exclude amplifiers, which involve one-way action; so our treatment more general than the usual network theories, in which amplifiers are sup- sed absent, resulting in certain symmetries in the circuit relations. Voltages d currents in amplifiers which are proportional to other voltages or currents , of course, not considered as *impressed*, even though they are derived from parate sources of energy; for they are taken into account by transfer *imped- ces*. A similar consideration applies to voltages and currents of negative- stance devices.

† Equation 3 together with this statement constitutes Thévinin's theorem.

** These curves are the *ovals of Cassini*, each of which is characterized by the property that the product of the distances from any point on it to 2 fixed points is a constant. As may be seen from the discussion immediately following (figure 2*b*), the distance from any point to the "short-circuit point" *A* represents E_L/z_S; and $(E_L/z_S)I_L = A_L/z_S$, which is constant. A special case is the *lemniscate*, drawn heavily in figure 1*a*.

Our problem is thus reduced to that of finding the loci of $\boldsymbol{I}_L$ under various restrictions. The restrictions that we shall consider are that each of the 10 following real quantities in the adjustable branch shall in turn remain *fixed* at various values: current, I_L; voltage, E_L; their phase difference, ϕ_L; active power, $P_L = E_L I_L \cos \phi_L$; reactive power, $Q_L = E_L I_L \sin \phi_L$; impedance, $z_L = E_L/I_L$; resistance, $r_L = z_L \cos \phi_L$; reactance, $x_L = z_L \sin \phi_L$; conductance, $g_L = (1/z_L) \cos \phi_L$; susceptance, $b_L = (1/z_L) \sin \phi_L$. We shall find that the loci in each case form a set of circles and that all of these sets of circles are related to a *single framework* (figure 2) made up of 4 fixed points (O, A, B, C) and the 6 straight lines joining them, as follows: for fixed I_L, E_L, P_L or Q_L, the centers of the circles lie on one of the 4 points; while for fixed ϕ_L, z_L, r_L, x_L, g_L, or b_L, the centers of the circles lie on one of the 6 straight lines. (Figure 2 is drawn for the case where r_S and x_S, the rectangular components of $\boldsymbol{z}_S$, are both positive, as is most usual.)

The locus for any fixed magnitude I_L of *current* $\boldsymbol{I}_L$ is obviously a circle having its center at the origin O and the radius I_L, figure 2*b*.

The locus for fixed magnitude E_L of *voltage* is found almost as directly: If we write equation 3 in the form,

$$\boldsymbol{I}_L = \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S} - \frac{\boldsymbol{E}_L}{\boldsymbol{z}_S}, \quad \text{or} \quad \boldsymbol{I}_L = \boldsymbol{I}_{LS} - \frac{\boldsymbol{E}_L}{\boldsymbol{z}_S}, \tag{5}$$

we see that the vectors corresponding to the 3 terms form a triangle, as in figure 2*b*, of which the vertex A also is fixed, since the short-circuit current, $\boldsymbol{I}_{LS} = \boldsymbol{E}_{L0}/\boldsymbol{z}_S$, is fixed. Then if the magnitude E_L is fixed, the magnitude of $\boldsymbol{E}_L/\boldsymbol{z}_S$ will also be fixed; so the locus will be a circle having its center at the short-circuit point A and the radius E_L/z_S.

The *active power* $P_L = E_L I_L \cos \phi_L$ is found by multiplying I_L by the projection of $\boldsymbol{E}_L$ upon $\boldsymbol{I}_L$. If ϕ_{L0} is the phase difference between $\boldsymbol{E}_{L0}$ and $\boldsymbol{I}_L$ and if r_S is the real part of $\boldsymbol{z}_S$, this projection is $E_{LS} \cos \phi_{LS} - I_L r_S$, as illustrated by the usual vector diagram, figure 2*a*. So

$$P_L = I_L(E_{L0} \cos \varphi_{L0} - I_L r_S), \text{ whence } \cos \varphi_{L0} = \frac{I_L^2 + P_L/r_S}{I_L E_{L0}/r_S} \tag{6}$$

To show that with fixed P_L this gives a circular current locus, we may derive the general polar equation of a circle, as illustrated in figure 3. There the well-known "cosine law" of trigonometry gives

$$\cos(\theta - \alpha) = \frac{R^2 + a^2 - b^2}{2Ra} \tag{7}$$

This is of the same form as equation 6, the correspondence being as follows:

Variables, $I_L = R$, $\varphi_{L0} = \theta$; constants, $\frac{P_L}{r_S} = a^2 - b^2$, $\frac{E_{L0}}{r_S} = 2a$, $0 = \alpha$.

Hence the locus for fixed P_L is a circle whose center is on the $\boldsymbol{E}_{L0}$ vector ($\alpha = 0$) at the fixed distance

$$a = \frac{E_{L0}}{2r_S} \tag{8}$$

and whose radius is

$$b = \left(a^2 - \frac{P_L}{r_S}\right)^{1/2} = \left(\frac{E_{L0}^2}{4r_S^2} - \frac{P_L}{r_S}\right)^{1/2} \tag{9}$$

Such a set of circles is illustrated in figure 2*c*, with centers at B. If P_L is positive (power input into the adjustable branch), then $a > b$ and the circle does not enclose the origin. If P_L is negative (power output), then $a < b$ and the circle encloses the origin. If $P_L = 0$, then $a = b$ and the circle passes through the origin, as shown by the heavily drawn circle C_P in figure 2*c*. There will be a maximum possible value of P_L, corresponding to $b = 0$, which is

$$P_{Lm} = \frac{E_{L0}^2}{4r_S} \tag{10}$$

This corresponds to the common center B, which may thus be called the *maximum-active-power point.*

The loci for fixed *reactive power* Q_L are found in exactly similar fashion, Q_L being given (figure 2*a*) by the equation,

$$Q_L = I_L(E_{L0} \sin \varphi_{L0} - I_L x_S), \text{ whence } \sin \varphi_{L0} = \cos\left(\varphi_{L0} - \frac{\pi}{2}\right) = \frac{I_L^2 + Q_L/x_S}{I_L E_{L0}/x_S}, \tag{11}$$

where x_S is the imaginary part of $\boldsymbol{z}_S$. The loci are again concentric circles, their centers being at the distance

$$a = \frac{E_{L0}}{2x_S} \tag{12}$$

on the line lagging 90 degrees behind $\boldsymbol{E}_{L0}$, and their radii being

$$b = \left(a^2 - \frac{Q_L}{x_S}\right)^{1/2} = \left(\frac{E_{L0}^2}{4x_S^2} - \frac{Q_L}{x_S}\right)^{1/2} \tag{13}$$

as also illustrated in figure 2*c*, with centers at C. If Q_L is positive (inductive), the circle does not enclose the origin; if it is negative (capacitive), the circle does enclose the origin; and if $Q_L = 0$, the circle passes through the origin, as shown by the heavily drawn circle C_Q, figure 2*c*. There will be a maximum possible value of Q_L, corresponding to $b = 0$, which is

$$Q_{Lm} = \frac{E_{L0}^2}{4x_S} \tag{14}$$

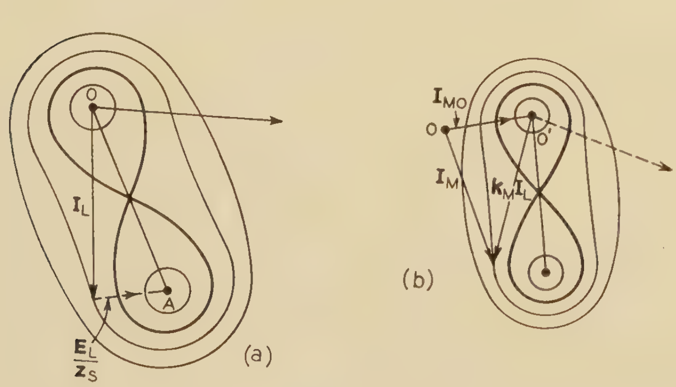


Fig. 1

his corresponds to the common center C, which may us be called the *maximum-reactive-power point.*

The 4 fixed points O, A, B, C, which we have now cated, and the 6 straight lines joining them make up e framework to which we referred earlier. In the bsequent loci (figure 2d, e, f), each of these straight

$$\cos(-\theta' - \alpha) = \frac{m}{R'} + nR' \quad \text{or} \quad \cos(\theta' + \alpha) = nR' + \frac{m}{R'} \tag{16}$$

which is of the same form as (15) but with α replaced by $-\alpha$ and with m and n interchanged. The locus of $\boldsymbol{R}'$ is therefore also a circle, as represented by C', figure 4a. (The dotted circle C_i is conveniently found first; it is

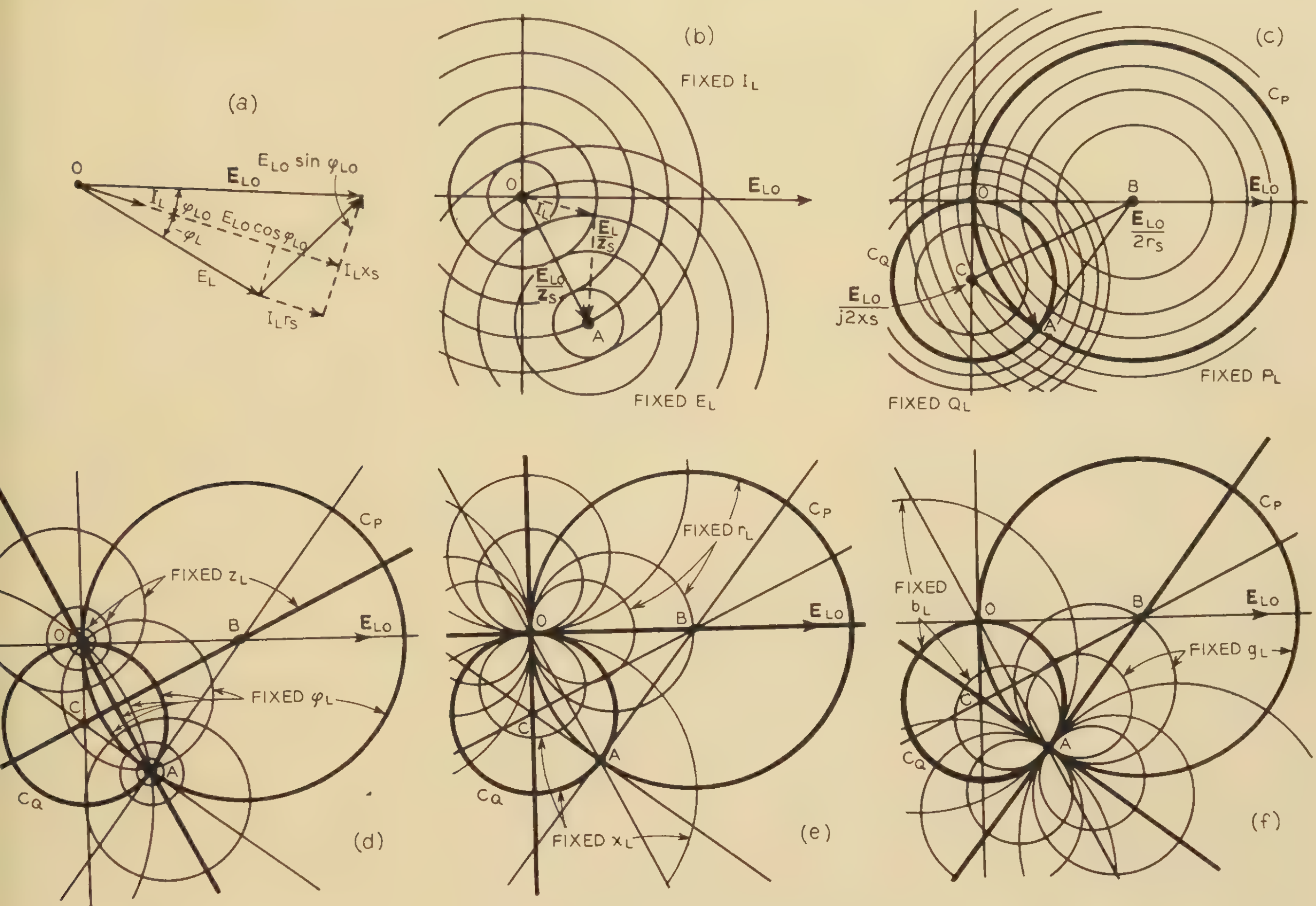


Fig. 2

es will appear as a special locus itself and also as earing the centers of a set of circular loci. The circles $_P$ and C_Q also reappear as loci in each of figures 2d, e, f, d are heavily drawn throughout.

The remaining sets of loci all depend on the property a circle that its *inverse* with respect to a point is also a rcle (including the limiting case of a straight line as a rcle of infinite radius). Let a complex variable, $\boldsymbol{R}$ = $\epsilon^{j\theta}$, have a circular locus C, so that R and θ are related equation 7. The reciprocal, $\boldsymbol{R}' = R'\epsilon^{j\theta'} = 1/\boldsymbol{R}$ = $/R)\epsilon^{-j\theta}$, then has the magnitude $R' = I/R$ and the ase angle $\theta' = -\theta$. If $a > b$, so that the circle C es not enclose the origin O, figure 4a, equation 7 may written in the form,

$$\cos(\theta - \alpha) = mR + \frac{n}{R} \tag{15}$$

here $m = 1/(2a)$ and $n = (a^2 - b^2)/(2a)$ are positive nstants.

Putting $\theta = -\theta'$ and $R = 1/R'$, we have

the inverse of C with respect to O, only the magnitude having been changed from R to R', not the angle θ.)

If $a < b$, so that the circle C encloses the origin O, figure 4b, equation 7 may be written in the form,

$$\cos(\theta - \alpha) = mR - \frac{n}{R} \tag{17}$$

where $m = 1/(2a)$ and $n = (b^2 - a^2)/(2a)$ are again positive constants. Then, putting $\theta = -\theta'$ and $R = 1/R'$, as before, we have

$$\cos(-\theta' - \alpha) = \frac{m}{R'} - nR' \text{ or } \cos(\theta' + \alpha - \pi) = nR' - \frac{m}{R'} \tag{18}$$

which is of the same form as (17) but with α replaced by $\pi - \alpha$ and with m and n interchanged. The locus of $\boldsymbol{R}'$ is therefore again a circle, as represented by C', figure 4b.

If $a = b$, so that the circle C passes through the origin O, figure 4c, equation (7) becomes

$$\cos(\theta - \alpha) = \frac{R}{2a} \tag{19}$$

So

$$\left.\begin{aligned} \cos(-\theta' - \alpha) &= \frac{1}{2aR'} \\ &\text{or} \\ R' \cos(\theta' + \alpha) &= \frac{1}{2a} \end{aligned}\right\} \quad (20)$$

which is evidently the equation of the straight line C', figure 4*c*.

(The theorem that the inverse of a circle is a circle can also be proved by elementary geometry, using the fact

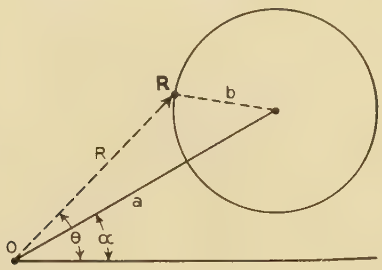


Fig. 3

that an inscribed angle is measured by its subtended arc to prove the similarity of certain triangles.)

The above theorem can be generalized to show that *if* $\boldsymbol{R}$ *has a circular locus, then so has the general linear fraction,*

$$\boldsymbol{w} = \frac{\boldsymbol{dR} + \boldsymbol{e}}{\boldsymbol{fR} + \boldsymbol{g}} \left(\boldsymbol{d}, \boldsymbol{e}, \boldsymbol{f}, \boldsymbol{g} \text{ are complex constants such that } \frac{\boldsymbol{d}}{\boldsymbol{f}} \neq \frac{\boldsymbol{e}}{\boldsymbol{g}}\right) \quad (21)$$

For this equation may be reduced by division to

$$\boldsymbol{w} = \frac{\boldsymbol{d}}{\boldsymbol{f}} + \frac{\boldsymbol{e} - \boldsymbol{dg}/\boldsymbol{f}}{\boldsymbol{fR} + \boldsymbol{g}} \quad (22)$$

Thus $\boldsymbol{w}$ is derived from $\boldsymbol{R}$ by the following steps, each of which turns one circle into another: multiplying by the constant $\boldsymbol{f}$ and adding the constant $\boldsymbol{g}$, thus changing the scale, rotating and translating the circle; inverting, giving a new circle as proved above; and multiplying by the constant $\boldsymbol{e} - \boldsymbol{dg}/\boldsymbol{f}$ and adding the constant $\boldsymbol{d}/\boldsymbol{f}$, thus changing the scale, rotating and translating the new circle.

Now returning to our problem of finding the loci of $\boldsymbol{I}_L$, we may put $\boldsymbol{E}_L = \boldsymbol{I}_L\boldsymbol{z}_L$ in equation 3, giving

$$\boldsymbol{I}_L = \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S + \boldsymbol{z}_L} \quad (23)$$

where

$$\boldsymbol{z}_L = z_L\epsilon^{j\varphi_L} = r_L + jx_L = \frac{1}{g_L - jb_L} \text{ is variable} \quad (24)$$

Evidently $\boldsymbol{I}_L$ is a linear fraction with respect to any of the components $\boldsymbol{z}_L$, $\epsilon^{j\varphi_L}$, x_L, r_L, b_L, or g_L when the associated component is held fixed. Hence in each case the locus of $\boldsymbol{I}_L$ will be a circle, as we have just proved. We proceed to consider each case in turn.

If the *phase difference* φ_L is fixed, and z_L varies, the vector $z_L\epsilon^{j\varphi_L}$ will have a straight-line locus (circle of infinite radius). The current is expressed in terms of φ_L and z_L by the equation,

$$\boldsymbol{I}_L = \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S + z_L\epsilon^{j\varphi_L}} \quad (25)$$

As z_L varies from 0 to ∞, $\boldsymbol{I}_L$ will vary from $\boldsymbol{E}_{L0}/\boldsymbol{z}_S$ to 0, for any φ_L; so all circular loci will pass through the origin O and the short-circuit point A, as drawn in figure 2*d*. Their centers will therefore lie on the line BC, which is the perpendicular bisector of OA. For very large z_L, the term $\boldsymbol{z}_S$ becomes vanishingly small in comparison with $z_L\epsilon^{j\varphi_L}$; so $\boldsymbol{I}_L$ starts off from O at the phase angle $-\varphi_L$, which is thus the inclination of the tangent to the circle at the origin. When $\varphi_L = 0$, we have the zero-active-power circle C_P; when $\varphi_L = 90$ degrees, we have the zero-reactive-power circle C_Q; and when $\varphi_L = \varphi_S$ (the phase angle of $\boldsymbol{z}_S$), we have the straight line OA.

If the *impedance* z_L is fixed and φ_L varies, the vector $z_L\epsilon^{j\varphi_L}$ will have a circular locus (since $\epsilon^{j\varphi_L}$ is a vector of unit length and variable angle). The current, given by 25, will then have a circular locus which is most easily located by finding its center and radius. Evidently $\boldsymbol{I}_L$ will have its minimum and maximum magnitudes when $\boldsymbol{z}_L$ is respectively in phase with, and in opposition to, $\boldsymbol{z}_S$; it then becomes

$$\left.\begin{aligned} \boldsymbol{I}_{L\,\min} &= \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S} \cdot \frac{1}{1 + \frac{z_L}{z_S}} \\ &\text{and} \\ \boldsymbol{I}_{L\,\max} &= \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S} \cdot \frac{1}{1 - \frac{z_L}{z_S}} \end{aligned}\right\} \quad (26)$$

The center of the circle is then the extremity of the vector,

$$\frac{\boldsymbol{I}_{L\,\min} + \boldsymbol{I}_{L\,\max}}{2} = \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S} \cdot \frac{1}{2}\left(\frac{1}{1 + \frac{z_L}{z_S}} + \frac{1}{1 - \frac{z_L}{z_S}}\right) = \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S} \cdot \frac{1}{1 - \frac{z_L^2}{z_S^2}} \quad (27)$$

so all centers lie on the line OA, which is the vector $\boldsymbol{E}_{L0}/\boldsymbol{z}_S$ produced. And the radius of the circle is the length of the vector,

$$\begin{aligned} \frac{\boldsymbol{I}_{L\,\max} - \boldsymbol{I}_{L\,\min}}{2} &= \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S} \cdot \frac{1}{2}\left(\frac{1}{1 - \frac{z_L}{z_S}} - \frac{1}{1 + \frac{z_L}{z_S}}\right) \\ &= \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S} \cdot \frac{z_L/z_S}{1 - \frac{z_L^2}{z_S^2}} \end{aligned} \quad (28)$$

For $z_L = 0$ and $z_L = \infty$, respectively, the circles shrink to the points A and O. For $z_L = z_S$, the circle has an infinite radius and becomes the straight line BC.

Inspection of figure 2*d* suggests that the 2 sets of circles are *orthogonal* (cross at right angles). To prove this, we may differentiate (23):

$$d\boldsymbol{I}_L = \frac{-\boldsymbol{E}_{L0}}{(\boldsymbol{z}_S + \boldsymbol{z}_L)^2} d\boldsymbol{z}_L \quad (29)$$

w if $d\boldsymbol{z}_L$ is given in turn 2 values at right angles, $d\boldsymbol{I}_L$ l also have 2 values at right angles, since the factor $\boldsymbol{E}_{L0}/(\boldsymbol{z}_S + \boldsymbol{z}_L)^2$ is the same for both. But when $\boldsymbol{z}_L$ ries first with φ_L fixed and then with z_L fixed, $d\boldsymbol{z}_L$ will t be radial and then tangential. Hence the corre- nding values of $d\boldsymbol{I}_L$ will be at right angles. This

circles inside C_P, negative values to circles outside. For $r_L = -r_S$, the circle has an infinite radius and becomes the straight line OC.

If the *reactance* x_L is fixed and r_L varies, the vector $\boldsymbol{z}_L = r_L + jx_L$ will again have a straight-line locus (now horizontal). The current, expressed by (30), will have

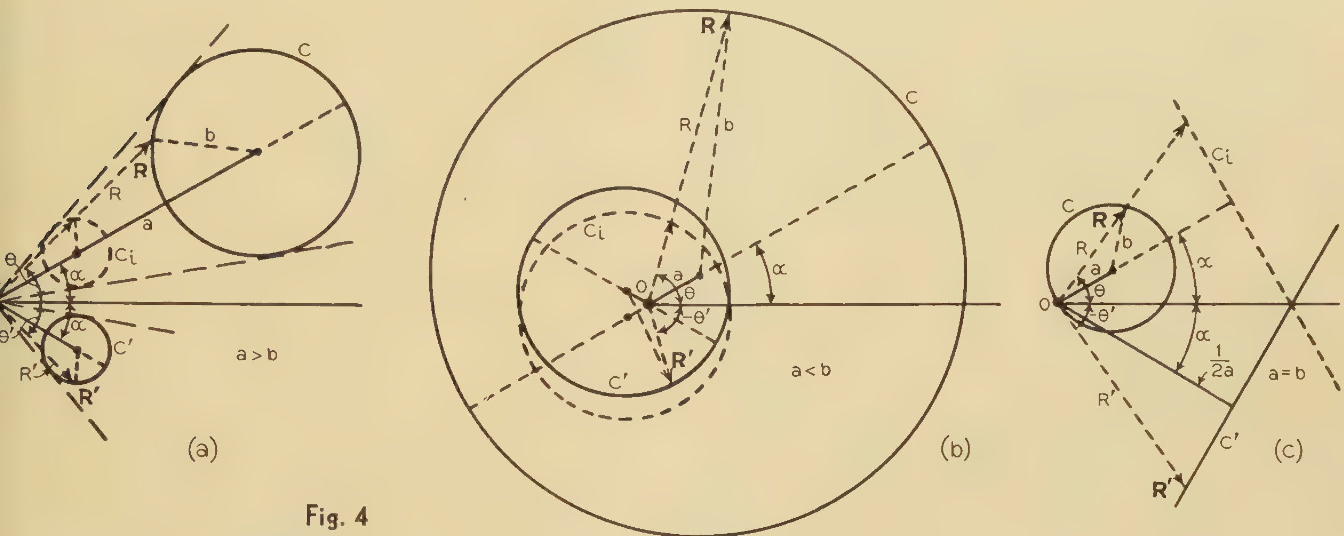


Fig. 4

ation affords a ready means for locating the constant-z_L cle passing through any point P in the plane: the nstant-φ_L circle is first drawn (through P, O, and A) d then its tangent is drawn at P; the intersection of is tangent with OA is the center of the required circle.*

If the *resistance* r_L is fixed and x_L varies, the vector $= r_L + jx_L$ will have a straight-line locus (vertical). e current is expressed in terms of r_L and x_L by the uation,

$$= \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S + r_L + jx_L} = \frac{\boldsymbol{E}_{L0}}{(r_S + r_L) + j(x_L + x_S)} \tag{30}$$

ere $\boldsymbol{z}_S = r_S + jx_S$.

If $x_L = \pm\infty$, $\boldsymbol{I}_L = 0$ for all r_L; so all circular loci will ss through the origin O. Evidently $\boldsymbol{I}_L$ will have its aximum magnitude when $x_L = -x_S$ and is then

$$_{\max} = \frac{\boldsymbol{E}_{L0}}{r_S + r_L} \tag{31}$$

e center of the circle is then the extremity of the vector,

$$\boldsymbol{I}_{L\max} = \frac{\boldsymbol{E}_{L0}}{2(r_S + r_L)} \tag{32}$$

all centers lie on the line OB, which is the vector $\boldsymbol{E}_{L0}$ oduced, as drawn in figure 2*e*. For $r_L = \pm\infty$, the cles shrink to the point O. For $r_L = 0$, the circle is zero-active-power circle C_P, whose radius was found be $E_{L0}/(2r_S)$. Positive values of r_L correspond to

a similar set of circular loci, all passing through O (for $r_L = \pm\infty$). It will have its maximum magnitude when $r_L = -r_S$ and is then

$$\boldsymbol{I}_{L\max} = \frac{\boldsymbol{E}_{L0}}{j(x_S + x_L)} \tag{33}$$

The center of the circle is then the extremity of the vector,

$$\frac{1}{2}\boldsymbol{I}_{L\max} = \frac{\boldsymbol{E}_{L0}}{j2(x_S + x_L)} \tag{34}$$

so all centers lie on the line OC, which is in quadrature with $\boldsymbol{E}_{L0}$, as drawn in figure 2*e*. For $x_L = \pm\infty$, the circles shrink to the point O. For $x_L = 0$, the circle is the zero-reactive-power circle C_Q, whose radius was found to be $E_{L0}/(2x_S)$. Positive (inductive) values of x_L correspond to circles inside C_Q, negative (capacitive) values to circles outside. For $x_L = -x_S$, the circle has an infinite radius and becomes the straight line OB.

The 2 sets of circles in figure 2*e* are orthogonal, for the same reason as in figure 2*d*. Equation 29 still applies; and $d\boldsymbol{z}_L$ will first be vertical and then horizontal when $\boldsymbol{z}_L$ is varied first with r_L fixed and then with x_L fixed.

If the *conductance* g_L is fixed and b_L varies, the vector $1/\boldsymbol{z}_L = g_L - jb_L$ will have a straight-line locus (vertical). It will now be convenient to temporarily shift our origin to A and to consider the locus of the vector (extending *from* A, figure 2*b*),

$$-\frac{\boldsymbol{E}_L}{\boldsymbol{z}_S} = -\frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S}\cdot\frac{\boldsymbol{z}_L}{\boldsymbol{z}_S + \boldsymbol{z}_L} = -\frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S^2}\cdot\frac{1}{\dfrac{1}{\boldsymbol{z}_S} + \dfrac{1}{\boldsymbol{z}_L}}$$

$$= -\frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_L^2}\cdot\frac{1}{(g_S + g_L) - j(b_S + b_L)} \tag{35}$$

we imagine $\boldsymbol{z}_L$ *mapped* in its plane by drawing radial lines (fixed φ_L) and centric circles (fixed z_L), these lines will constitute a figure *conformal* with loci of figure 2*d*. Conformal mapping of one figure on another requires that corresponding angles be equal. It always results when corresponding loci drawn for 2 complex variables one of which is an analytic (differentiable) ction of the other; for then differential figures will be similar. (Finite res, however, will be similar only in the special case where the function is *ar*, as in equation 1 and figure 1.)

where $1/\boldsymbol{z}_S = g_S - jb_S$. If $b_L = \pm\infty$, $-\boldsymbol{E}_L/\boldsymbol{z}_S = 0$ for all g_L; so all circular loci will pass through A. Evidently $-\boldsymbol{E}_L/\boldsymbol{z}_S$ will have its maximum magnitude when $b_L = -b_S$ and is then

$$-\frac{\boldsymbol{E}_{L\max}}{\boldsymbol{z}_S} = -\frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S^2}\cdot\frac{1}{g_S+g_L} \tag{36}$$

The center of the circle is then the extremity of the vector (from A),

$$-\frac{1}{2}\frac{\boldsymbol{E}_{L\max}}{\boldsymbol{z}_S} = -\frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S^2}\cdot\frac{1}{2(g_S+g_L)} \tag{37}$$

This vector evidently lags behind $-\boldsymbol{E}_{L0}/\boldsymbol{z}_S$ by the angle φ_S; so it lies along the line AB, on which therefore all centers lie, as drawn in figure 2*f*. For $g_L = \pm\infty$, the circles shrink to the point A. For $g_L = 0$, the circle is the zero-active-power circle C_P since then

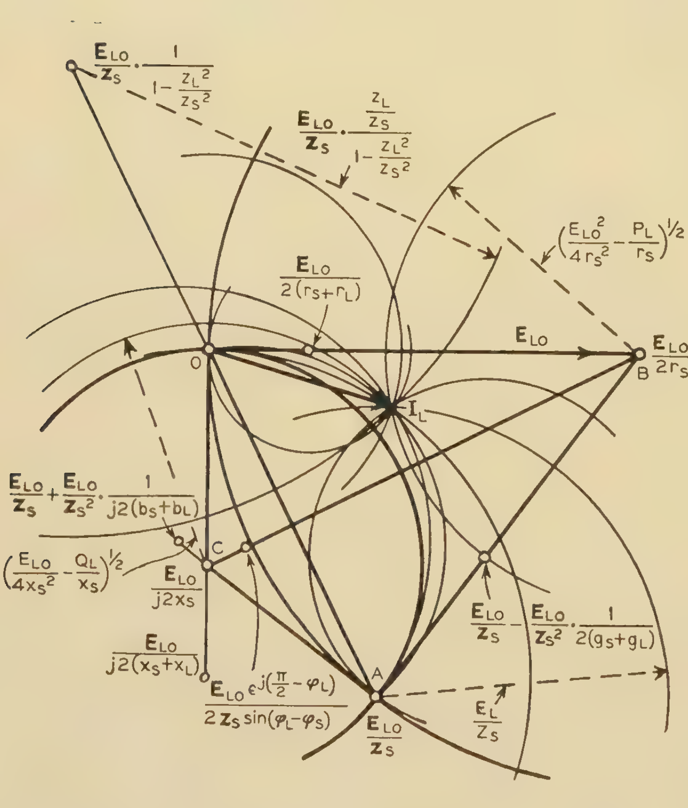
$$\frac{1}{2}\frac{E_{L\max}}{z_S} = \frac{E_{L0}}{z_S^2\cdot 2g_S} = \frac{E_{L0}}{2r_S} \tag{38}$$

as found for the radius of C_P. Positive values of g_L correspond to circles inside C_P, negative values to circles outside. For $g_L = -g_S$, the circle has an infinite radius and becomes the straight line AC.

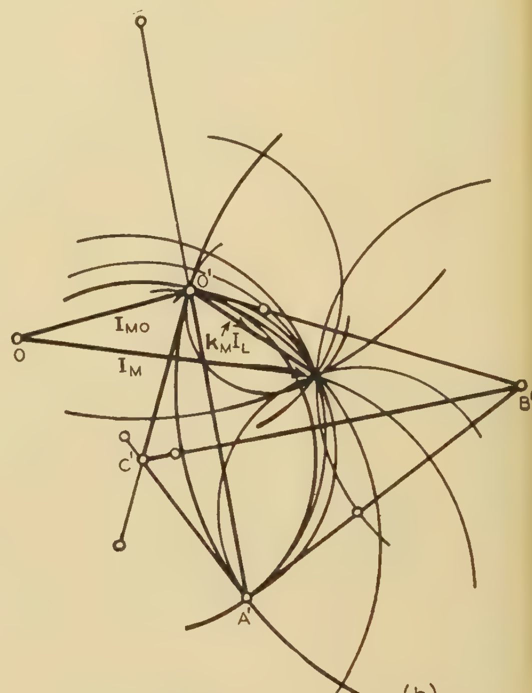
If the *susceptance* b_L is fixed and g_L varies, the vector $1/\boldsymbol{z}_L = g_L - jb_L$ will again have a straight-line locus (now horizontal). And $-\boldsymbol{E}_L/\boldsymbol{z}_S$, expressed by (35), will have a similar set of circular loci, all passing through A (for $g_L = \pm\infty$). It will have its maximum magnitude when $g_L = -g_S$ and is then

$$-\frac{\boldsymbol{E}_{L\max}}{\boldsymbol{z}_S} = \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S^2}\cdot\frac{1}{j(b_S+b_L)} \tag{39}$$

Fig. 5



(a)



(b)

The center of the circle is then the extremity of the vector (from A),

$$-\frac{1}{2}\frac{\boldsymbol{E}_{L\max}}{\boldsymbol{z}_S} = \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S^2}\cdot\frac{1}{j2(b_S+b_L)} \tag{40}$$

This vector is evidently in quadrature with the vector of equation 37; so it lies along the line AC (perpendicular to AB), on which therefore all centers lie, as drawn in figure 2*f*. For $b_L = \pm\infty$, the circles shrink to the point A. For $b_L = 0$, the circle is the zero-reactive-power circle C_Q, since then

$$\frac{1}{2}\frac{E_{L\max}}{z_S} = \frac{E_{L0}}{z_S^2\cdot 2b_S} = \frac{E_{L0}}{2x_S} \tag{41}$$

as found for the radius of C_Q. Positive (inductive) values of b_L correspond to circles inside C_Q, negative (capacitive) values to circles outside. For $b_L = -b_S$, the circle has an infinite radius and becomes the straight line AB.

The 2 sets of circles in figure 2*f* are orthogonal, for the same reason as in figure 2*d* and *e*. The equation which applies in this case is found by differentiating equation 35:

$$d\left(-\frac{\boldsymbol{E}_L}{\boldsymbol{z}_S}\right) = \frac{\boldsymbol{E}_{L0}}{\boldsymbol{z}_S^2}\cdot\frac{1}{\left(\frac{1}{\boldsymbol{z}_S}+\frac{1}{\boldsymbol{z}_L}\right)^2}\, d\left(\frac{1}{\boldsymbol{z}_L}\right) \tag{42}$$

for $d(1/\boldsymbol{z}_L)$ will first be vertical and then horizontal when $1/\boldsymbol{z}_L$ is varied first with g_L fixed and then with b_L fixed.

In figure 5*a* we have drawn (to double the scale of figure 2) for a particular current vector $\boldsymbol{I}_L$ the 10 loci which pass through its extremity, values of the radii and locations of the centers being indicated, for convenience of reference. Figure 5*b* is derived from figure 5*a* by multiplying all vectors by the constant $\boldsymbol{K}_M$ and adding the constant $\boldsymbol{I}_{M0}$, to give $\boldsymbol{I}_M$, in accordance with equation 1. This concludes our general problem.

A Suggested Rotor Flux Locus Concept of Single-Phase Induction-Motor Operation

By C. T. BUTTON
ASSOCIATE AIEE

THE cross field theory and the revolving field theory are the 2 commonly accepted bases for analytical treatment of the single phase squirrel cage induction otor. For the purpose of quantitative analysis as well to explain why and how the motor runs, the first menned theory resolves fluxes, voltages, and currents into mponents in 2 axes fixed with reference to the stator; hereas the second theory resolves the flux into 2 rotating mponents—one rotating in a positive direction at synronous speed, and the other rotating in a negative diction at synchronous speed.

An alternative concept is outlined below which is perps less involved than either of the above theories, alough it does not lend itself to quantitative mathematical eatment. In a word, it considers the total flux traversg the air gap, and gives a complete picture of the variaon in magnitude and direction of the total or resultant ıx. The novelty of the treatment consists in referring e flux to axes fixed with reference to the rotor. Once the ind of the reader becomes accustomed to thinking of the tor as a fixed basis of reference, the development bemes quite clear and rational. (The rotor may be rerded as stationary with the stator rotating about it, or it assists in visualizing one can imagine he is hanging to e rotor and turning around with it.)

ssumptions

Inasmuch as quantitative results are not attempted, ator resistance and leakage reactance will either not be volved, or will be considered zero. For purposes of simlifying the diagrams, a 2 pole motor will be considered igure 1). Motor torque will be considered as clockwise. he flux crossing the air gap in the axis of the stator windg poles will be called primary flux. At synchronous eed the axis of the primary flux will accordingly be rotting with an angular velocity of $2\pi f$ in a counterclockwise nse, with respect to axes of reference fixed in relation to e rotor.

ondition at Synchronous Speed

We may first plot the locus of the primary magnetomove-force vector with reference to the rotor for the synronous speed condition, as indicated in figure 2. This ay also be considered as representing the locus of flux rough the rotor if there were no rotor conductors; or s representing the primary flux as defined above. (If the otor were at standstill, the flux locus would of course be straight line, the instantaneous magnitude of the flux ulsating sinusoidally positive and negative with respect time.) At synchronous speed, this primary magnetomotive-force or primary flux vector locus would be a circle as shown, never going below the horizontal (rotor) axis. The maximum primary flux is shown as F_M in figure 2; and one-eighth of a cycle later the vector would be in the position shown dotted. The locus would be traversed (in a C.C.W. sense) by the vector twice per cycle, although its angular velocity is only $2\pi f$, as stated above.

The effect produced by the rotor conductors may be described as follows. The rotor is an inductive body circularly symmetrical, so to speak. It is evident that the effect of rotor inductance (not the leakage reactance) will be to resist any change in magnitude or direction of the total flux through it. In other words, due to change in magnitude and direction of the primary flux (figure 3) currents will flow in the rotor conductors producing a secondary flux at right angles to the primary flux; and this secondary flux will have a magnitude and direction tending to maintain the total resultant rotor flux constant at OF. At the instant when the primary flux is zero, the secondary flux will be a maximum, and perpendicular upward. This of course simply means that (to use ordinary terminology) the cross field is maximum when the main field is zero.

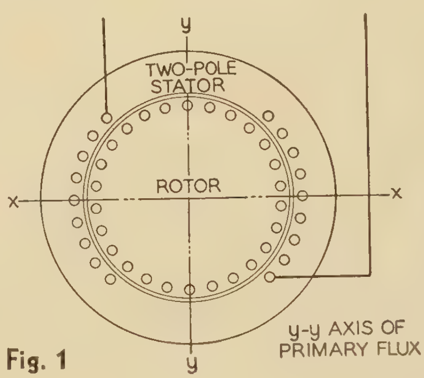


Fig. 1

The inductive effect of the rotor will not be 100 per cent in maintaining constant flux through the rotor at synchronous speed of course, due to the effect of rotor resistance and leakage reactance. The actual total rotor flux at synchronous speed in the practical motor will then be something like the locus indicated in figure 4.

The concept which this treatment attempts to visualize does not emphasize the components OM and MF of figure 3; but rather states simply that (to reiterate) the inductive effect of the rotor resists the amount of total flux change which would exist in an open-circuited rotor condition for the same rotor speed, constraining the total flux to the circular locus of small diameter shown in figure 4.

(It might be mentioned however, that in addition to the main and cross field components, we could also indi-

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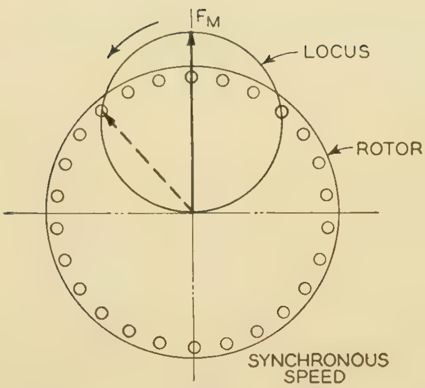

Fig. 2

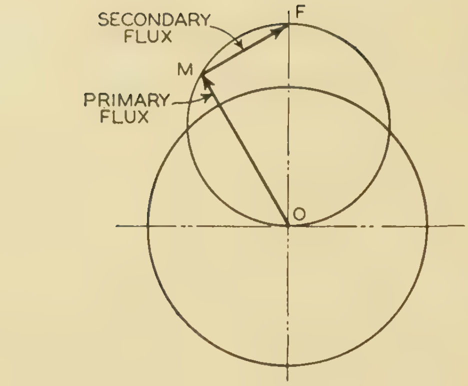

Fig. 3

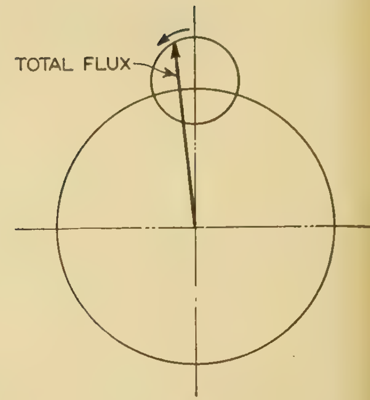

Fig. 4

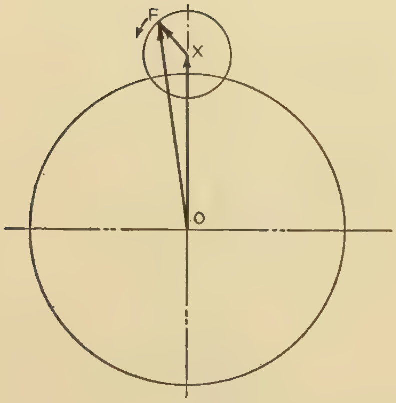

Fig. 5

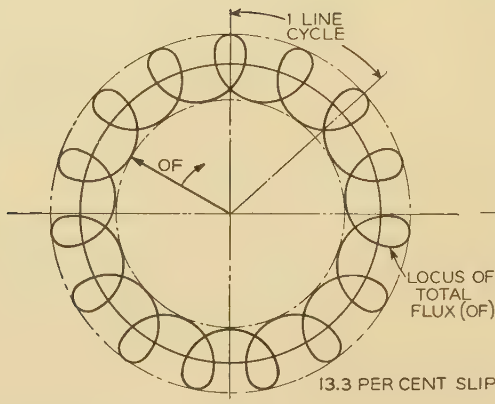

Fig. 6

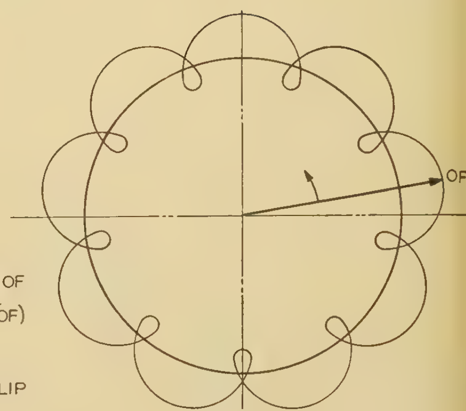

Fig. 7

cate on our diagram the forward and backward rotating flux components OX and XF as in figure 5. OX is constant, and XF is constant in magnitude and rotating with a velocity of $4\pi f$. Again, there is no motive for separation into components except possibly to tie in our diagrams with both of the theories mentioned at the outset.)

Normal Motoring Condition

It is now but a step to the conception of the locus of total flux at any particular amount of slip. This is shown by figure 6, where the flux vector progresses around the rotor in a clockwise sense (taking 2 steps forward and one step backward, so to speak).

Torque is produced by change in direction of flux through the rotor. The instantaneous torque will be a function of flux magnitude and angular velocity (torque would not be directly proportional to angular velocity of course). Inspection of figure 4 will show that at synchronous speed there is a pulsating torque with a net or average counter clockwise value. In other words, it requires power input to drive the motor at synchronous speed even with losses neglected. Or in still other words, the no load point is at some speed slightly below synchronism.

With normal slip, inspection of the corresponding flux locus (figure 6) will reveal the existence and reason for the pulsating double frequency torque component, and also the average motor torque.

The magnitude of the main flux will be the radius of the outer envelope of the total flux locus; and the quadrature flux will be represented by the radius of the inner envelope.

Conditions Above Synchronous Speed

In the same way, the total flux locus at a speed above synchronism may be drawn as shown by figure 7.

Conclusion

It is not claimed that the concepts outlined may be of direct use in calculating performance of single phase motors. However, it is important to have clear mental pictures of just what is going on in any machine under consideration. Such concepts may serve to assist in interpreting results obtained from mathematical treatment, and they may also serve a purpose in connection with general educational work.

The rotor is conceived of briefly as an inductive "circularly symmetrical" rotating body which tends to maintain total flux constant in magnitude and direction with respect to itself. This inductive effect prevents total flux from disappearing at the instant the primary field is zero; and its resistance to change in direction of total flux through it produces torque. The reason for the pulsating and average motor torque components is thus clearly visualized, by reference to the diagrams showing the behavior of the "mutual reactance flux" through stator and rotor.

Characteristic Constants of Single-Phase Induction Motors
Part I: Air-Gap Reactances

By WAYNE J. MORRILL
MEMBER AIEE

ynopsis

This paper is the first of 2 papers dealing with the de-elopment of equations for determining the characteristic onstants of single-phase induction motors. It is in-nded to present in the complete paper a unified tabula-on of formulas consistent in symbols with those used in e paper which I presented at the midwinter convention the AIEE, New York, January 28–February 1, 1929.

This particular section of the paper deals with a rigor-is development of the reactances of single-phase motors hich result from fluxes crossing the air gap between the ator and rotor.

ntroduction

SINCE 1929 great strides have been made in the design and development of the capacitor motor. As evidence of this fact, the capacitor motor is ow the accepted motor for use on domestic refrigeration achines and many other domestic appliances. During e last year over 1,000,000 such motors were built in e United States.

It is felt that at this time a further contribution to the t can be made by presenting in one paper a systematic evelopment consistent within itself, covering the method calculating the electrical characteristic constants of ngle-phase induction motors.

It is hoped that such a complete and consistent pres-tation of the matter will be useful in view of the fact at most of the previous information on the subject has een based upon polyphase formulas adapted to single-iase construction.

While the constants as developed in this paper are in-nded primarily for use in conjunction with the theory the capacitor motor and the resistance split-phase otor, the point of view of the development is such as furnish calculational methods which apply equally ell to other types of single phase motors as, for example, e repulsion-start induction-run single-phase motor.

lan of Development

The plan of the development follows closely that em-oyed by Chapman for polyphase induction motors and lger for synchronous motors except, that the single-iase point of view is maintained throughout and the sults apply especially to single-phase motors.

The development has as its basis the assumption that ly flux of fundamental space distribution links mutually e rotor and stator. Harmonic fluxes are assumed to be self-inductive to the members producing them and their effect is treated as that of self-inductive leakage reactance.

It is shown that spiraling either member reduces the effectiveness of the fundamental flux of one member as regards the other member while having no effect upon the producing member. It follows that where relative spiraling exists between the stator and the rotor the mutual reactance is reduced and since the self-inductive reactance is unchanged there must be effective in each member a component of leakage reactance due to self produced flux of fundamental space distribution. Expressions for exact determination of these effects are derived.

Results of Development

There results from the development an exact definition of 6 primary reactances and 5 secondary reactances. Only 3 of each are useful in actual calculation, the others being used in the development and for the sake of clarity. The constants and their derived formulas are listed in the tabulation below and their significance indicated by the accompanying equivalent circuits.

For the primary, the reactances defined are:

Primary Air-Gap Reactances

X_{T_1} = total primary self-inductive reactance due to air-gap flux
X_{m_1t} = total primary self-inductive reactance due to fundamental flux (both forward and backward)
X_{m_1} = total primary self-inductive reactance due to either fundamental field
$X_{1\delta t}$ = total primary self-inductive reactance due to harmonic flux
$X_{\alpha_1 t}$ = total primary self-inductive reactance due to spiral
X_m = primary mutual reactance of either forward or backward field

Secondary Air-Gap Reactances

X_{T_2} = total secondary self-inductive reactance to a revolving field
X_{m_2} = secondary self-inductive reactance due to fundamental flux
$X_{2\delta}$ = secondary self-inductive leakage reactance due to air-gap flux
X_α = secondary self-inductive leakage reactance due to spiral
X_m = secondary mutual reactance (with primary) to either field

Nomenclature

All of the nomenclature is defined in the course of the development. For convenience those symbols needed in interpreting the results are listed below.

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Wayne J. Morrill is engineer in charge of design in the fractional horsepower motor engineering division of the General Electric Company, Fort Wayne, Ind.

f = line frequency, cycles per second
f_T = function of primary turns. See remarks preceding (18)
K = $2\pi f 10^{-8}$
l = axial length of air gap section in inches
m_2 = total number of rotor slots
$\mathcal{P}$ = A/δ
A = effective air-gap area per square inch
δ = radial length of air gap in inches
P = number of fundamental poles
T_pW_k = primary effective turns per pole. See (11) and (12)
λ = fundamental peripheral pole pitch in inches
λ_α = peripheral distance in inches by which one end of spiraled member is displaced from its other end. See (40)

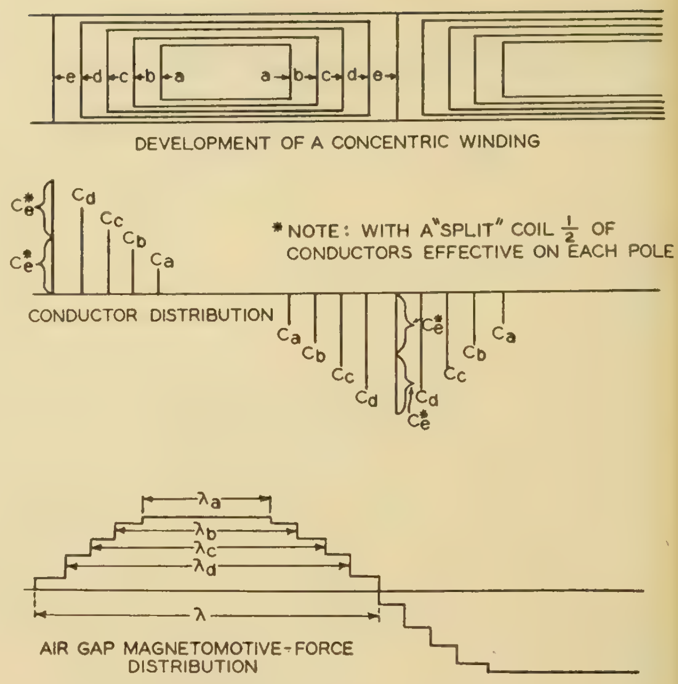

Fig. 2. Development of a concentric winding

Appendix—Development of Expressions for Reactance

General Assumptions in the Development of Equations for Air-Gap Reactances

The usual assumptions which are made in the exact analysis of induction motors and which are listed in the appendix of my 1929 paper are made in this paper and will not be repeated.

In determining the air-gap reactances of induction motors, however, there are certain assumptions in addition to those already mentioned which must be made for the sake of establishing a simple and exact method of attack. These assumptions are listed below.

(*a*) *Only air gap flux of fundamental sinusoidal space distribution links mutually the rotor and stator winding.* This is true because unless the number of slots in the rotor and stator are made multiples of each other, or the stator winding is carelessly proportioned, experience and theory both show that harmonic fluxes of one winding generate negligible fundamental voltages in the other winding. It is true that the harmonic fluxes of one winding may generate voltages of other than fundamental frequency in the other winding under certain conditions, but the phenomena involved may be treated independently of the fundamental theory of the motor, and therefore, are not touched upon in the present report.

(*b*) *Only that portion of the stator fundamental flux which produces voltage in the rotor winding, and only that portion of the rotor fundamental flux which produces voltage in the stator winding, are considered as mutual fluxes.* The test for mutual flux is that it must generate the same voltage per turn in one member as in the other member, and if this condition is not fulfilled the effect of reduction in voltage in the second member is that of leakage flux and must be so treated.

(*c*) *Those fluxes which are produced by one member and which do not produce fundamental voltage in the other member are treated as leakage fluxes.* From this point of view the difference, between the total flux of any winding and that portion of the flux which generates fundamental voltage in the opposite winding is defined as leakage flux.

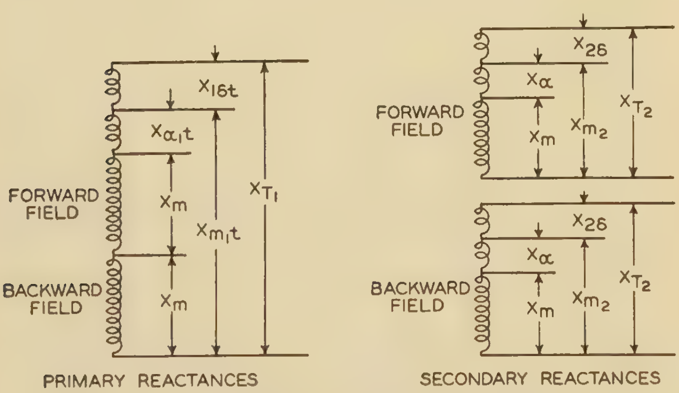

Fig. 1. Summary of air-gap reactances

$$X_{T_1} = K\mathcal{P}l\lambda f_T \qquad (18)$$

$$X_{m_1t} = \frac{8}{\pi^2}K\mathcal{P}l\lambda(T_pW_k)^2 \qquad (13)$$

$$X_{m_1} = \frac{4}{\pi^2}K\mathcal{P}l\lambda(T_pW_k)^2 \qquad (15)$$

$$X_{1\delta t} = X_{m_1}\left[\frac{\frac{\pi^2}{8}f_T}{(T_pW_k)^2} - 1\right] \qquad (20)$$

$$X_{\alpha_1 t} = X_{m_1}2\left[1 - \frac{2}{\pi}\frac{\lambda}{\lambda_\alpha}\sin\frac{\lambda_\alpha}{\lambda}\frac{\pi}{2}\right] \qquad (48)$$

$$X_m = X_{m_1}\frac{2}{\pi}\frac{\lambda}{\lambda_\alpha}\sin\frac{\lambda_\alpha}{\lambda}\frac{\pi}{2} \qquad (51)$$

$$X_{T_2} = X_{m_2} + X_{2\delta}$$

$$X_{m_2} = X_{m_1} \qquad (39)$$

$$X_{2\delta} = X_{m_1}\left[\left(\frac{P}{m_2}\,\frac{\pi}{2\sin\frac{P\pi}{2m_2}}\right)^2 - 1\right] \qquad (38)$$

$$X_\alpha = X_{m_1}\left[1 - \frac{2}{\pi}\frac{\lambda}{\lambda_\alpha}\sin\frac{\lambda_\alpha}{\lambda}\frac{\pi}{2}\right] \qquad (47)$$

I—Air-Gap Leakage Reactance of a Concentric Stator Winding

The primary windings of single-phase induction motors are invariably of the concentric type (coaxial coils of varying pitch) as shown in figure 2.

The total air-gap reactance of one pole of a concentric type winding can be obtained by taking the summation of the reactances corresponding to each stator tooth and the turns surrounding it. The general equation for the tooth reactance is

$$X_{tn} = K\mathcal{P}l\lambda_{tn}(\Sigma_n T)^2 \qquad (1)$$

where

l = axial length of air gap
X_{tn} = reactance due to "*n*th" tooth flux
K = constant to convert to ohms
λ_{tn} = peripheral pitch of "*n*th" tooth section
$\Sigma_n T$ = sum of turns surrounding "*n*th" tooth section
$\mathcal{P}$ = permeance per square inch of air gap (see nomenclature)

By reference to figure 2 it is possible to write the expression for

e reactance corresponding to the innermost teeth whose total ripheral pitch is λ_a.

$$a = K \mathcal{P} l \lambda_a (T_a + T_b + T_c + T_d + T_e)^2 \quad (2)$$

On each side of the λ_a section there are 2 sections of total periph-al pitch $\lambda_b - \lambda_a$. The reactance due to these sections is:

$$b = K \mathcal{P} l (\lambda_b - \lambda_a)(T_b + T_c + T_d + T_e)^2 \quad (3)$$

By the same method of reasoning the remaining reactances may determined and the total reactance becomes:

$$T_1 = K \mathcal{P} l \lambda \begin{bmatrix} \frac{\lambda_a}{\lambda}(T_a + T_b + T_c + T_d + T_e)^2 \\ \frac{\lambda_b - \lambda_a}{\lambda}(T_b + T_c + T_d + T_e)^2 \\ \frac{\lambda_c - \lambda_b}{\lambda}(T_c + T_d + T_e)^2 \\ \frac{\lambda_d - \lambda_e}{\lambda}(T_d + T_e)^2 \\ \frac{\lambda - \lambda_d}{\lambda}(T_e)^2 \end{bmatrix} \quad (4)$$

If only the air-gap magnetomotive-force distribution of the nth imary coil is considered, a diagram as shown in figure 3 is obtained.

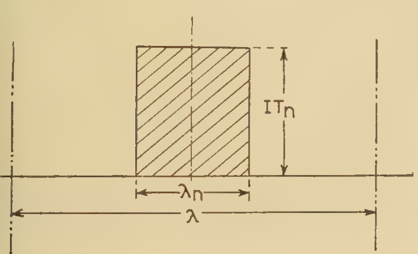

Fig. 3. Air-gap magnetomotive force of nth primary coil

y Fourier analysis it is possible to express the amplitude of the rresponding fundamental component of magnetomotive-force, a_n:

$$= \frac{4}{\pi} IT_n \sin \frac{\pi}{2} \frac{\lambda_n}{\lambda} \quad (5)$$

By the use of (5) the amplitude of the fundamental component magnetomotive-force due to all the coils on a pole may be written:

$$= \Sigma a_n \quad (6)$$

$$= \frac{4}{\pi} I \begin{bmatrix} T_a \sin \frac{\pi}{2} \frac{\lambda_a}{\lambda} \\ T_b \sin \frac{\pi}{2} \frac{\lambda_b}{\lambda} \\ T_c \sin \frac{\pi}{2} \frac{\lambda_c}{\lambda} \\ T_d \sin \frac{\pi}{2} \frac{\lambda_d}{\lambda} \\ T_e \sin \frac{\pi}{2} \frac{\lambda_e}{\lambda} \end{bmatrix}$$

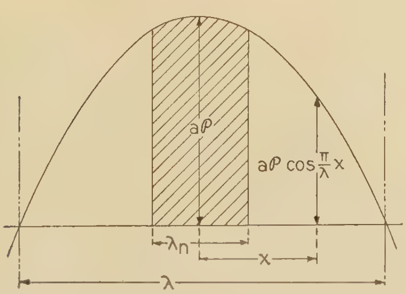

Fig. 4. Distribution of fundamental flux

The flux density at any point on the air gap periphery corre-onding to a magnetomotive-force wave having a maximum ampli-de of a may be expressed:

$$= a \mathcal{P} \cos \frac{\pi}{\lambda} x \quad (7)$$

where

B = flux density at point x
$\mathcal{P}$ = permeance per square inch of air gap

The portion of fundamental flux which links the nth stator coil can be obtained by multiplying equation (7) by the axial length in inches l and integrating between the limits of $-\frac{\lambda_n}{2}$ and $+\frac{\lambda_n}{2}$ as indicated in (8). This is the equivalent of finding the flux cross hatched in figure 4.

$$\Phi_{1n} = \int_{-\lambda_n/2}^{+\lambda_n/2} a \mathcal{P} l \cos \frac{\pi}{\lambda} x dx \quad (8)$$

$$\Phi_{1n} = a \mathcal{P} l \frac{\lambda}{\pi} \left[\sin \frac{\pi}{\lambda} x \right]_{-\lambda_n/2}^{+\lambda_n/2}$$

$$\Phi_{1n} = 2a \mathcal{P} l \frac{\lambda}{\pi} \sin \frac{\pi}{2} \frac{\lambda_n}{\lambda} \quad (9)$$

The reactance of the nth stator coil due to the fundamental flux which links it may be expressed by multiplying (9) by the number of turns in the coil, T_n, and by K/I to convert to ohms.

$$X_{1n} = 2a \mathcal{P} l \frac{\lambda}{\pi} \frac{K}{I} T_n \sin \frac{\pi}{2} \frac{\lambda_n}{\lambda} \quad (10)$$

The total reactance of the stator winding due to the self-produced fundamental flux is obtained as the sum of X_{1n} for all coils:

$$X_{m_1 t} = 2a \mathcal{P} l \frac{\lambda}{\pi} \frac{K}{I} \begin{bmatrix} T_a \sin \frac{\pi}{2} \frac{\lambda_a}{\lambda} \\ T_b \sin \frac{\pi}{2} \frac{\lambda_b}{\lambda} \\ T_c \sin \frac{\pi}{2} \frac{\lambda_c}{\lambda} \\ T_d \sin \frac{\pi}{2} \frac{\lambda_d}{\lambda} \\ T_e \sin \frac{\pi}{2} \frac{\lambda_e}{\lambda} \end{bmatrix} \quad (11)$$

The bracketed member of (6) and (11) is termed the "effective turns" per pole of the primary winding and is symbolized by:

$$\text{Effective turns per pole} = T_P W_K \quad (12)$$

where

T_P = total turns per pole
W_K = winding constant to convert to "effective turns"

If (6) and (12) are substituted in (11) the following is obtained:

$$X_{m_1 t} = \frac{8}{\pi^2} \mathcal{P} l \lambda K (T_p W_k)^2 \quad (13)$$

Equation (13) expresses the total reactance of the primary winding due to pulsating self produced flux of fundamental sinusoidal distribution.

It has long been known that a pulsating wave of sinusoidally distributed flux may be represented by 2 equal oppositely gliding waves of flux each having a constant amplitude equal to half the amplitude of the pulsating wave. In my 1929 paper I defined the magnetizing reactance of a single-phase motor as that value of reactance corresponding to either of the gliding fields of flux. In equation (19) of that paper its value was given as:

$$X_{m_1} = 2\pi f C_m^2 \frac{1}{16} \mathcal{P} l \lambda 10^{-8} \quad (14)$$

In the present case, since the reactance due to each gliding (or revolving) wave of flux has the same value, the primary reactance

due to either must be equal to half the total primary magnetizing reactance:

$$X_{m_1} = \frac{1}{2} X_{m_1t} \tag{15}$$

$$X_{m_1} = \frac{4}{\pi^2} \mathcal{P} l \lambda K (T_p W_k)^2$$

If the following substitutions are made in (14) and (15) the 2 equations will be found to be identical.

$$C_m = \frac{8}{\pi} T_p W_k \tag{16}$$

$$K = 2\pi f 10^{-8} \tag{17}$$

It will be found convenient in the present paper to express as many air-gap reactances as possible in terms of per unit of X_{m_1}.

If the bracketed member of (4) be called f_T (function of turns), the equation for x_{T_1} is:

$$X_{T_1} = K \mathcal{P} l \lambda f_T \tag{18}$$

Equation (18) expresses the total reactance of the primary winding due both to the flux of fundamental sinusoidal distribution and the leakage flux which is of other than fundamental distribution. The reactance due to air-gap leakage flux may, therefore, be expressed as the difference between the total reactance and the total reactance due to the fundamental flux:

$$X_{1\delta t} = X_{T_1} - X_{m_1t} \tag{19}$$

Expressed in terms of X_{m_1} the total per-unit leakage reactance due to air gap flux is:

$$\text{Per unit } X_{1\delta t} = \frac{X_{T_1} - X_{m_1t}}{X_{m_1}} \tag{20}$$

$$\text{Per unit } X_{1\delta t} = 2\left[\frac{\frac{\pi^2}{8} f_T}{(T_p W_k)^2} - 1\right] \tag{21}$$

Equation (21) is a dimensionless formula and because of its dimensionless character gives a clear picture of the relationships involved. In order to obtain the actual total primary air-gap leakage reactance it is necessary to multiply (21) by X_{m_1}

The Air-Gap Leakage Reactance of a Rotor With Uniformly Spaced Slots Wound One Phase per Slot

In the case of a motor of the repulsion-start induction-run type, the rotor winding employed during running operation is a winding having as many phases as there are slots in the rotor. If the rotor has an even number of slots or a number of slots corresponding to a multiple of the number of poles, certain of these phases may be repetitions of each other, but the analysis to be presented will be found to include such special cases.

If a rotor of the type described be acted upon by a revolving field of stator flux, the voltages generated in succeeding coils (phases) and the currents which result will have a peripheral distribution in the rotor slots as shown in figure 5. The upper diagram indicates the slot distribution of the ampere conductors of the left hand sides of the coils and the lower diagram indicates the ampere-conductor distribution of the right-hand coil sides. The sum of these 2 diagrams furnishes the total ampere-conductors distributed in each slot.

Proceeding from the distribution shown in figure 5, it is possible to develop 2 magnetomotive-force distribution diagrams as shown in figure 6. The sum of these 2 diagrams furnishes the resultant magnetomotive-force distribution produced by the rotor winding.

It is possible to express analytically the ampere-conductor distribution in the rotor slots due to the left coil sides shown in the upper diagram, figure 5.

$$I_{nL} C_c = I_{2n\,\max}\, C_c \cos \frac{P\lambda}{m_2} n \frac{\pi}{\lambda} \tag{22}$$

where

C_c = conductors per coil side
I_{nL} = amperes per conductor in left side of nth coil
$I_{2n\,\max}$ = maximum amperes per conductor in rotor coils
n = integer indicating the number of the rotor phase under consideration, starting with a rotor phase carrying maximum current as the zero phase and counting in a forward direction
P = number of fundamental poles
λ = pole pitch in inches
m_2 = number of rotor phases (total)

The equation for the ampere-conductor distribution in the nth slot due to the right-hand coil side is very similar to that of the left-hand coil side except displaced by a difference corresponding to the coil pitch and reversed in sign. This distribution is given by equation 23.

$$I_{nR} C_c = -I_{2n\,\max}\, C_c \cos \frac{P\lambda}{m_2} (n - t_c) \frac{\pi}{\lambda}$$

t_c = number of rotor teeth included by one rotor coil (23)

The sum of equation (22) and (23) gives the total ampere-conductor distribution in the nth rotor slot.

$$I_n C_c = (I_{nL} + I_{nR}) C_c =$$

$$I_{2n\,\max}\, C_c \left[\cos \frac{P\lambda}{m_2} n \frac{\pi}{\lambda} - \cos \frac{P\lambda}{m_2} (n - t_c) \frac{\pi}{\lambda}\right] \tag{24}$$

The sum of the ampere-conductors in each of the slots from the "zero" slot to the nth slot is the number of ampere-conductors tending to produce flux across the air gap from the face of the nth tooth.

$$MMF_n = \sum_0^n I_{2n\,\max}\, C_c \left[\cos \frac{P\pi}{m_2} n - \cos \frac{P\pi}{m_2} (n - t_c)\right] \tag{25}$$

$$MMF_n = I_{2n\,\max}\, C_c \left[\frac{\cos \frac{P\pi}{2m_2} (2n + 1 - t_c) \sin \frac{P\pi}{2m_2} t_c}{\sin \frac{P\pi}{2m_2}}\right] \tag{26}$$

The flux in the nth tooth which will be produced by MMF_n may

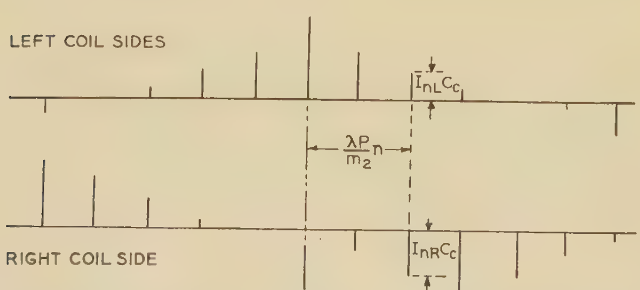

Fig. 5. Rotor slot ampere-conductor distribution

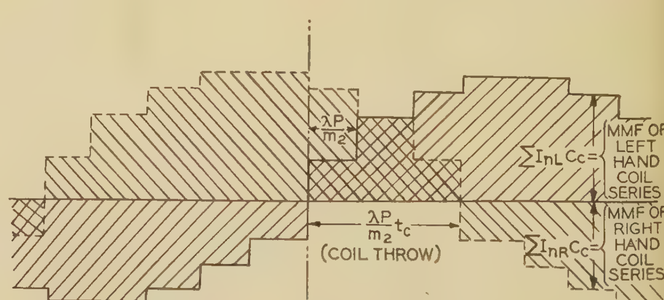

Fig. 6. Rotor-air-gap magnetomotive force distribution

obtained by multiplying MMF_n by the permeance per tooth. an be expressed as in (27).

$$= MMF_n \frac{\lambda P l}{m_2} \mathcal{P} =$$

$$I_{2n\ \max} C_c \frac{\lambda P l}{n} \mathcal{P} \left[\frac{\cos \frac{P\pi}{2m_2} (2n + 1 - t_c) \sin \frac{P\pi}{2m_2} t_c}{\sin \frac{P\pi}{2m_2}} \right] \quad (27)$$

he total flux per pole is the sum of the fluxes in each tooth across pole face:

$$= \sum_{0}^{\frac{m_2}{P}-1} \Phi_n = I_{2n\ \max} C_c \frac{\lambda P l}{m_2} \mathcal{P} \left[\frac{\sin \frac{P\pi}{2m_2} t_c}{\sin \frac{P\pi}{2m_2}} \right] \quad (28)$$

= axial length of air gap
= permeance per square inch of air gap

he amplitude of the fundamental component of the rotor flux be obtained by Fourier analysis. In figure 7 is shown the of one rotor tooth. The amplitude of the fundamental sine ponent of this flux will be derived. (Due to the choice of axis cosine component drops out in taking a summation of the sine cosine components across one pole and the cosine component is, refore, being omitted.)

he amplitude of the fundamental sine component of the flux wn in figure 7 is given by the expression of equation (29) which be converted to (30) and (31).

$$\int_0^{\lambda} \sin^2 \frac{\pi}{\lambda} x dx = \int_{\frac{\lambda p}{m_2} n}^{\frac{\lambda p}{m_2}(n+1)} MMF_n \mathcal{P} \sin \frac{\pi}{\lambda} x dx \quad (29)$$

$$= -\frac{2}{\pi} MMF_n \mathcal{P} \left[\cos \frac{\pi P}{m_2} (n + 1) - \cos \frac{\pi P}{m_2} n \right] \quad (30)$$

$$= \frac{4\mathcal{P}}{\pi} I_{2n\ \max} C_c \left[\frac{1}{2} \sin \frac{\pi P}{2m_2} (4n + 2 - t_c) + \frac{1}{2} \sin \frac{\pi P}{2m_2} t_c \right] \sin \frac{\pi P}{2m_2} t_c \quad (31)$$

he value of $a_{\Phi n}$ is the maximum density of the sine component the flux of the nth rotor tooth. To obtain the amplitude of the al sine component the summation of $a_{\Phi n}$ across one pole pitch is en:

$$= \sum_{0}^{\frac{m_2}{P}-1} a_{\Phi n} \quad (32)$$

$$= \frac{4\mathcal{P}}{\pi} I_{2n\ \max} C_c \frac{m_2}{P} \left[\frac{1}{2} \sin^2 \frac{\pi P}{2m_2} t_c \right] \quad (33)$$

he quantity a_Φ is the maximum amplitude of the fundamental component produced by the rotor winding. In order to express value of the flux it is necessary to integrate the wave correspond- to a_Φ over one pole pitch and for an axial length, l.

$$= \int_0^{\lambda} la \sin \frac{\pi}{\lambda} x dx = \frac{2}{\pi} \lambda a \quad (34)$$

$$= \frac{4}{\pi^2} l\lambda \mathcal{P} I_{2n\ \max} C_c \frac{m_2}{P} \sin^2 \frac{\pi P}{2m_2} t_c \quad (35)$$

ince all the currents which produce both Φ_{m_2} and Φ_{T_2} vary usoidally with respect to time, Φ_{m_2} and Φ_{T_2} vary sinusoidally h respect to time and their difference, $\Phi_{T_2} - \Phi_{m_2}$, varies in the e fashion. All of these fluxes completely link each rotor bar, since all of them are of the same frequency with respect to the rotor they generate voltages of the same frequency which referred to the stator winding is the fundamental frequency of the motor.

Since, with a given value of current, the magnitude of reactance is proportional to generated voltage, the total rotor-air-gap reactance (referred to primary) X_{T_2} and the fundamental rotor air gap reactance X_{m_2} must be proportional respectively to the total rotor air gap flux Φ_{T_2} and the fundamental air gap flux Φ_{m_2}.

$$\frac{X_{T_2}}{X_{m_2}} = \frac{\Phi_{T_2}}{\Phi_{m_2}} \quad (36)$$

In the same way that the per-unit air-gap leakage reactance of the primary was defined we may write

$$\text{Per unit } X_{2\delta} = \frac{X_{T_2} - X_{m_2}}{X_{m_2}} = \frac{\Phi_{T_2} - \Phi_{m_2}}{\Phi_{m_2}} \quad (37)$$

If the values for Φ_{T_2} and Φ_{m_2} be substituted from (28) and (35) respectively equation (38) is obtained.

$$\text{Per unit } X_{2\delta} = \frac{I_{2n\ \max} C_c \frac{\lambda P l}{m_2} \mathcal{P} \left[\frac{\sin \frac{P\pi}{2m_2} t_c}{\sin \frac{P\pi}{2m_2}} \right]^2}{I_{2n\ \max} C_c \lambda l \mathcal{P} \frac{m_2}{P} \sin^2 \frac{\pi P}{2m_2} t_c} \quad (38)$$

Equation (38) simplifies to:

$$\text{Per unit } X_{2\delta} = \left(\frac{P}{m_2}\right)^2 \frac{\pi}{4 \sin^2 \frac{P\pi}{2m_2}} - 1 \quad (39)$$

Equation (39) expresses the rotor-air-gap leakage reactance in per unit of X_{m_2} but a valuable simplification can be made if it be recognized that:

$$X_{m_2} = X_{m_1} \quad (40)$$

This is true because the dimensions of the magnetic circuits of X_{m_2} and X_{m_1} are the same and X_{m_2} is "referred to the primary," which means that the effective turns are the same.

The Air-Gap Reactance Due to Spiral

Thus far in the discussion of the air-gap reactances of single-phase induction motors only fluxes of other than fundamental distribution have acted in the rôle of leakage fluxes. We come now to a reactance caused by flux of fundamental distribution.

If one of the members (stator or rotor) of an induction motor is spiraled, no change is produced in either the fundamental air-gap flux reactance or the total air-gap reactance as far as the spiraled member is concerned. There is, however, a change in the effectiveness of the spiraled flux in inducing voltage in the other member and since the proof of mutual flux is that it induce equal volts per turn at the same frequency in both members, it must be concluded that the reduced effectiveness of the primary flux is a leakage-reactance phenomenon.

The equation for the 3-dimension wave of flux when the producing member is spiraled is given by (41).

$$B = MMF_{\max} \mathcal{P} \cos \left[\frac{\pi}{\lambda} \left(x - \frac{\lambda_\alpha}{l} z \right) - \omega t \right] \quad (41)$$

λ_α = peripheral amount by which one end of the spiraled member is displaced from the other end
z = axial distance measured from one end of spiraled member toward the other end
l = axial length of air gap

The voltage per conductor generated in the unspiraled member is equal to the integral of the rate of change of the flux as z varies from zero to l.

$$E_{c\alpha} = \int_0^l K_e MMF_{\max} \mathcal{P} \frac{d}{dt} \cos \left[\frac{\pi}{\lambda} \left(x - \frac{\lambda_\alpha}{l} z \right) - \omega t \right] dz \quad (42)$$

$$E_{c\alpha} = K_e MMF_{\max}\, \mathcal{P}\, \omega \frac{\lambda}{\pi} \frac{l}{\lambda_\alpha} \left\{ \begin{array}{l} \cos\left[\frac{\pi}{\lambda}(x - \lambda_\alpha) - \omega t\right] \\ - \cos\left[\frac{\pi}{\lambda} x - \omega t\right] \end{array} \right\} \quad (43)$$

$$E'_{c\alpha} = 2K_e MMF_{\max}\, \mathcal{P}\, \omega \frac{\lambda}{\pi} \frac{l}{\lambda_\alpha} \times$$

$$\sin\left[\frac{\pi}{\lambda}\left(x - \frac{\lambda_\alpha}{2}\right) - \omega t\right] \sin \frac{\lambda_\alpha}{\lambda} \frac{\pi}{2} \quad (44)$$

Equation (44) indicates the voltage per conductor generated in the unspiraled member by the spiraled flux. The voltage which would be generated in the same conductor by the same fundamental flux if there were no spiral can be obtained from (44) by allowing λ_α to approach zero as a limit. This voltage is given by equation (45).

$$E_c = K_e MMF_{\max}\, \mathcal{P} \omega l \sin\left(\frac{\pi}{\lambda} x - \omega t\right) \quad (45)$$

The ratio of the mutual fundamental flux to the self-inductive fundamental flux must be equal to (44) divided by (45)

$$\frac{\Phi_m}{\Phi_{m_1}} = \frac{2}{\pi} \frac{\lambda}{\lambda_\alpha} \sin \frac{\lambda_\alpha}{\lambda} \frac{\pi}{2} \quad (46)$$

The ratio of the leakage flux of fundamental distribution to the fundamental flux must, therefore, be:

$$\frac{\Phi_{m_1} - \Phi_m}{\Phi_{m_1}} = \left[1 - \frac{\Phi_m}{\Phi_{m_1}}\right] = 1 - \frac{2}{\pi} \frac{\lambda}{\lambda_\alpha} \sin \frac{\lambda_\alpha}{\lambda} \frac{\pi}{2} \quad (47)$$

The ratio expressed in (47) is also the ratio of the leakage reactance to the primary fundamental air-gap reactance.

$$\text{Per unit } X_\alpha = \left[1 - \frac{2}{\pi} \frac{\lambda}{\lambda_\alpha} \sin \frac{\pi}{2} \frac{\lambda_\alpha}{\lambda}\right] \quad (48)$$

In order to obtain either the primary or secondary forward or backward field leakage reactance due to spiral it is necessary to multiply (48) by X_{m_1}. Since each stator phase produces a forward field of flux just equal to its backward field the total primary reactance due to spiral is equal to twice the spiral reactance of either field:

$$X_{\alpha_1 t} = 2X_\alpha = 2X_{m_1}\left[1 - \frac{2}{\pi} \frac{\lambda}{\lambda_\alpha} \sin \frac{\pi}{2} \frac{\lambda_\alpha}{\lambda}\right] \quad (49)^*$$

The rotor forward-field flux is not equal to its backward-field flux and the value X_{α_2} must be introduced separately into the equivalent circuit for each field.

It is obvious from the development that it makes no difference which member is spiraled in so far as the resultant effect upon the mutual flux and the leakage-reactance fluxes are concerned.

Mutual Magnetizing Reactance Due to Fundamental Flux

In connection with the reactance due to spiral, it should be further noticed that the reduction in fundamental flux effectiveness mentioned at the start of the spiral reactance discussion amounts to a reduction in X_m, the mutual flux reactance. The reduction is precisely the same as the leakage reactance due to spiral for that is the way the spiral reactance was defined. If there is no spiral:

$$X_m = X_{m_1} \text{ when there is no spiral} \quad (50)$$

When relative spiral exists the mutual reactance, X_m is reduced.

$$X_m = X_{m_1}[1 - \text{Per unit } X_\alpha] \quad (51)$$

$$X_m = X_{m_1} \frac{2}{\pi} \frac{\lambda}{\lambda_\alpha} \sin\left(\frac{\lambda_\alpha}{\lambda} \frac{\pi}{2}\right) \quad (52)$$

It will be noticed that when the spiral is equal to twice the pole pitch the fundamental mutual magnetizing reactance becomes zero and all the fundamental air gap flux produced by the primary winding acts as leakage flux.

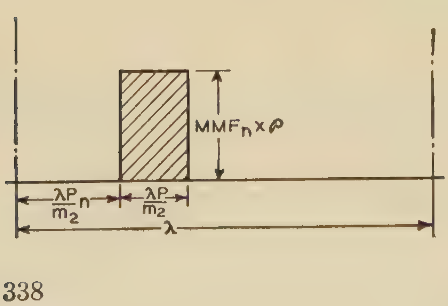

Fig. 7. Flux distribution from rotor tooth

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POLYPHASE MOTORS

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2. CALCULATION OF ARMATURE REACTANCE OF SYNCHRONOUS MACHINES, P. L. Alger. AIEE TRANSACTIONS, volume 47, 1928, pages 493–512.

* It is important to notice that only when the primary phases are in quadrature, as is usual with capacitor motors and split-phase motors, can X_{α_1} be treated as a self-inductive reactance. Under other conditions X_{α_1} becomes mutual with other primary phases.

Rectifier Circuit for Measurement of Small Power-Angle Oscillations

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KNOWLEDGE of transient oscillations of synchronous machines is of considerable importance because of the application of such information to studies on ystem load changes which may lead to loss of synchronism, voltage fluctuations, or to hunting. Although in many istances very large angular swings must be taken into ccount, for many investigations only relatively small igular swings are considered. In this latter class are roblems of determining the effects of saturation on ad angle, angular variations with attendant current ulsations for variable torque loads, and the prediction stability under large load changes as determined from udies of loads causing small displacements.

Rotor swinging has been observed under stroboscopic lumination, and displacement angles have been recorded a motion picture camera taking 30 frames per second sed in conjunction with the stroboscope.[1] A mark on a oving field pole may be followed exactly in its oscillaons, a plot of displacements shown on the films yielding e time-angle relation of the rotor. Rotor oscillations so have been determined by means of a pilot alternator rect connected to the shaft of the main machine.[2] In is case, 2 phases (single-phase line-to-line voltages), e from each machine, are tied together at one end, and e rotor and voltage of the pilot alternator so adjusted at the voltage difference between the other 2 phase rminals is zero at the reference angle, which may be for ro or any specified load. The voltage difference apearing under load is a direct measure of the corresponding splacement angle, and the voltage carried to an oscilgraph results in a wave of line frequency with a varying nplitude if the rotor is swinging.

The first method, although by far the best, because it ves the displacement angle directly under all conditions operation, involves apparatus not generally available. he second method has the disadvantages of requiring auxiliary alternator and a replot of the test data. Osllations about a reference axis introduce a change of iase which may be difficult to determine under some nditions. In addition, the difference voltage is not oportional to angle outside a region of 60 electrical grees. This last disadvantage, however, is eliminated ien studies are confined to small angular displacements, many investigations are.

ne Circuit

It is probable that the second method is more readily aptable to studies undertaken in most laboratories beuse of availability of equipment, in which case it then is convenience to have the oscillograph plot the actual splacement curve directly rather than the wave of system frequency with varying amplitude. The full wave rectifier tube is well suited to this problem because of the practically linear relationship between the plate current and the applied voltage. The addition of a filter circuit to reduce the unidirectional pulsations at line frequency to an average value greatly simplifies the resulting oscillogram.

With a single rectifier and filter circuit driven by the voltage difference between the pilot alternator and the machine under investigation, there results a single trace on the oscillogram the amplitude of which is directly proportional to the difference voltage. The magnitude of

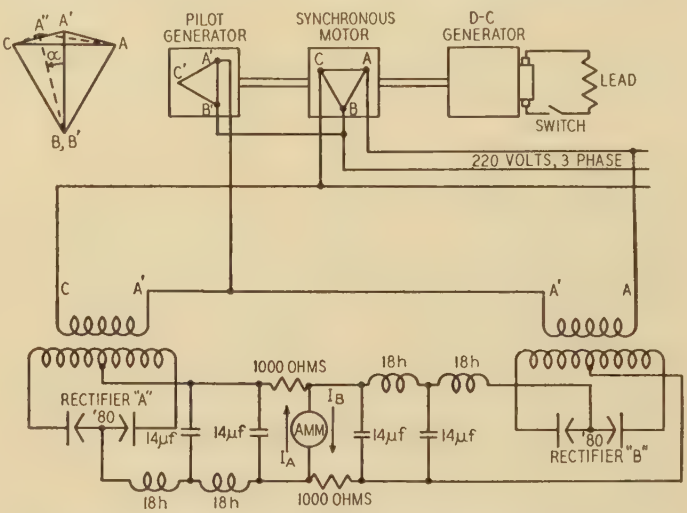

Fig. 1. Rectifier circuit for determination of angular oscillations of a synchronous machine

the difference voltage is proportional to sin ($\alpha/2$) where α is the displacement angle between the machine terminal voltage and the pilot alternator voltage. As the sine of the angle is almost proportional to the angle itself for the range between 0 and 30 degrees, this circuit will give practically linear deflections up to torque-angles of 60 electrical degrees. All of the deflections, however, are above the zero axis, those for negative as well as for positive angles because of the characteristics of the rectifier. This difficulty may be overcome if 2 such circuits are used in opposition and are driven by 2 such difference voltages equal in magnitude at the reference angle. At the zero position the currents will balance out, the current through

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1. For all numbered references see list at end of paper.

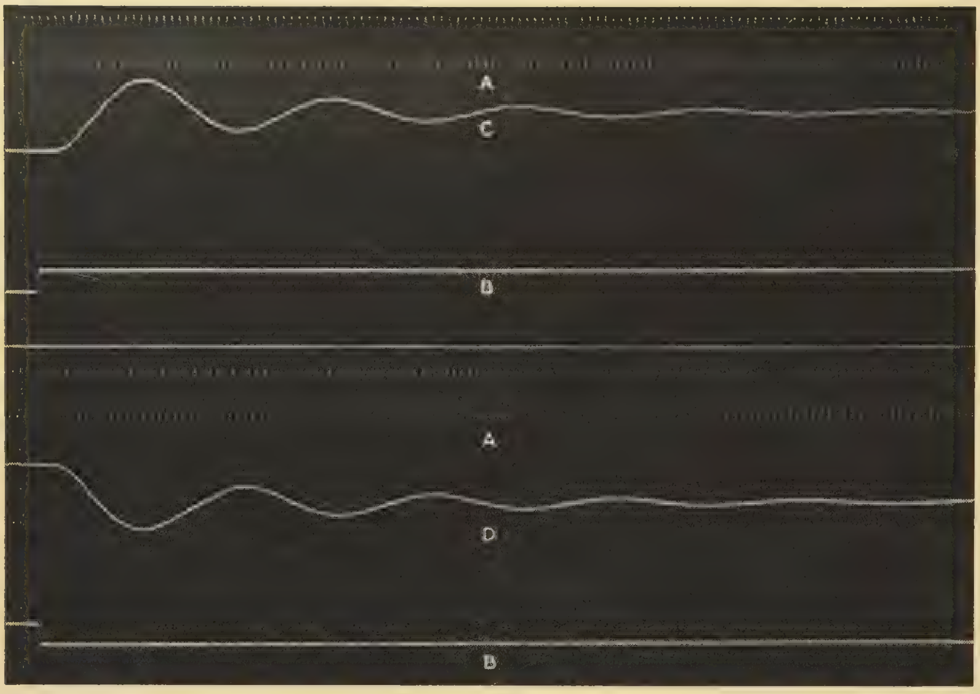

Fig. 3. Oscillograms showing angular oscillations of a synchronous motor under sudden load changes

A—60-cycle timing wave
B—Load current
C—Machine angle, load applied (20.5 electrical degrees maximum angle)
D—Machine angle, load dropped (8.5 electrical degrees initial angle)

the oscillograph element being zero for this rotor position. The circuit is shown in figure 1.

Circuit Action

The line voltages of the motor under observation are represented by the sides of the triangle ABC. The single-phase voltage, $B'A'$, of the pilot alternator represents the rotor position of the motor. This voltage is made equal in magnitude to the line voltage of the motor, and is adjusted in phase so that it lies midway between the line voltages BA and BC. The difference voltages, CA' and AA', are equal and produce equal rectifier currents, I_A and I_B, which are in opposition, thus resulting in zero current through the instrument.

If a load is applied to the motor shaft there will be an angular displacement between the stator magnetomotive force and rotor poles which will be indicated by a shift in position of the pilot alternator voltage through the angle α, i.e., from $B'A'$ to $B'A''$. The new rectifier voltages will be CA'' and AA'', resulting in an increased voltage on rectifier B and a decreased voltage on rectifier A. I_B will increase, I_A will decrease, and the instrument or oscillograph will indicate a current equal to the new difference. In this discussion it is assumed that the machine under investigation is connected to an infinite bus. Practically, a drop of 5 per cent in line voltage will introduce about a 2 per cent error in the difference voltage.

The characteristic curves of each rectifier, and the resulting characteristic, are given in figure 2. It will be observed that if the displacement angle is greater than 30 electrical degrees both rectifier voltages will increase with angle, and the oscillograph current will remain constant, being the difference of 2 increasing currents. This circuit eliminates any question on change of phase. The filter circuit, with the constants as given in figure 1, may be relied upon with an error not over one per cent for oscillations of the rotor up to 4.5 cycles per second. This is a frequency of rotor swing much higher than normally would be found for either large or small machines.

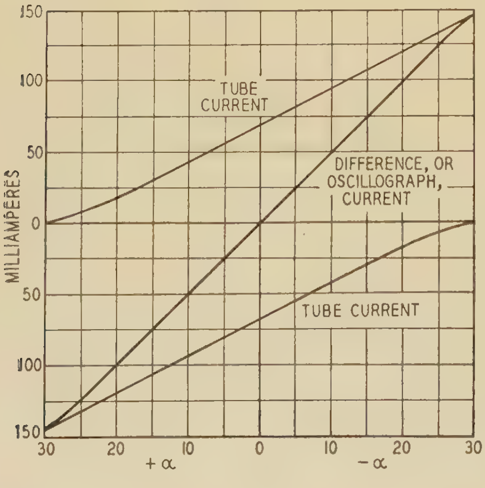

Fig. 2. Characteristic curves for rectifier circuit showing tube currents and difference current as functions of angle α

The oscillograms of figure 3 illustrate the application of the device just described, and show the angular oscillations of a synchronous motor as load is thrown on and off. The pilot alternator had an adjustable stator, thus allowing ready phase adjustment between the 2 machines, although a phase shifting transformer or a wound rotor induction motor with rotor blocked may be employed. Angle calibration may be obtained with a stroboscope, from a vector diagram for the difference voltages, from a calibrated phase shifting device, or perhaps by calculation from the power-angle relation for the motor.

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Current and Voltage Loci in 3-Phase Circuits Part III: Δ-Y Connection

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ntroduction

T HAS been shown that the method of circular loci may be conveniently applied to obtain the variation of currents and voltages when self-impedances are changed in rious types of circuits operated at constant frequency. rt I[1] dealt with this problem in a Y-Y connection and rt II[2] in a Δ-Δ connection. In both of these papers rrent equations were given involving all the impedces and voltages of the most general types of Y-Y and -Δ circuits and required only the substitution of nuerical values to obtain the locus of any current or volte existing in the system. The same treatment will now applied to the Δ-Y connection.

he Δ-Y Circuit

In figure 1 is shown the general Δ-Y circuit. Internal ltages of like frequency are assumed to exist in both urce and load phases and to have any magnitude and ase angle. Self impedances are considered in the internnecting lines as well as in the source and in the load. r the sake of generality mutual impedances are assumed the source and load and also between the lines. There e no restrictions on the values of any of the self- and utual-impedance elements other than they be linear and lateral.

Equations will be set up for the 6 phase currents which in is case also include the 3 line currents. The voltages in e system will be obtained by adding internal voltages to propriate impedance drops.

Adding the potential differences about meshes $a102ba$, $03cb$, and $c301ac$, and summing up the currents about nctions, o, a, and b, the requisite equations are:

$$A_1 + I_2A_2 + I_3A_3 + I_aZ_{aa} + I_bZ_{ab} + I_cZ_{ac} = K_1 \quad (1)$$

$$B_1 + I_2B_2 + I_3B_3 + I_aZ_{ba} + I_bZ_{bb} + I_cZ_{bc} = K_2 \quad (2)$$

$$C_1 + I_2C_2 + I_3C_3 + I_aZ_{ca} + I_bZ_{cb} + I_cZ_{cc} = K_3 \quad (3)$$

$$+ I_2 + I_3 = 0 \quad (4)$$

$$+ I_a - I_c = 0 \quad (5)$$

$$- I_a + I_b = 0 \quad (6)$$

which

$$\left.\begin{aligned}
&= Z_{rs} - Z_{rr} + Z_{12} - Z_{11}\\
&= Z_{st} - Z_{ss} + Z_{23} - Z_{22}\\
&= Z_{tr} - Z_{tt} + Z_{31} - Z_{33}\\
&= Z_{ss} - Z_{sr} + Z_{22} - Z_{21}\\
&= Z_{tt} - Z_{ts} + Z_{33} - Z_{32}\\
&= Z_{rr} - Z_{rt} + Z_{11} - Z_{13}\\
&= Z_{ts} - Z_{tr} + Z_{32} - Z_{31}\\
&= Z_{rt} - Z_{rs} + Z_{13} - Z_{12}\\
&= Z_{sr} - Z_{st} + Z_{21} - Z_{23}\\
&= E_{01} - E_{02} + E_{ab}\\
&= E_{02} - E_{03} + E_{bc}\\
&= E_{03} - E_{01} + E_{ac}
\end{aligned}\right\} \quad (7)$$

By Cramers' rule the currents may be expressed as

$$\left.\begin{aligned}
I_a &= \frac{\Delta I_a}{\Delta} & I_1 &= \frac{\Delta I_1}{\Delta}\\
I_b &= \frac{\Delta I_b}{\Delta} & I_2 &= \frac{\Delta I_2}{\Delta}\\
I_c &= \frac{\Delta I_c}{\Delta} & I_3 &= \frac{\Delta I_3}{\Delta}
\end{aligned}\right\} \quad (8)$$

Here Δ is the general determinant or the common denominator and ΔI_a, ΔI_b, etc., are the specific determinants obtained from the general determinant by replacing the coefficients of the current desired by the column of K's.

The expansions of the common denominator and the numerators follow below. It should be noted that although the mutual elements are bilateral, i.e., $Z_{23} = Z_{32}$, both sequences of subscripts are used in order to display the cyclicity of terms.

$$\begin{aligned}
\Delta = {} & (Z_{aa} + Z_{ab} + Z_{ac})\{-(B_2C_3 - B_3C_2) + (B_1C_3 - B_3C_1) - (B_1C_2 - B_2C_1)\} + \\
& (Z_{bb} + Z_{bc} + Z_{ba})\{(A_2C_3 - A_3C_2) - (A_1C_3 - A_3C_1) + (A_1C_2 - A_2C_1)\} + \\
& (Z_{cc} + Z_{ca} + Z_{cb})\{-(A_2B_3 - A_3B_2) + (A_1B_3 - A_3B_1) - (A_1B_2 - A_2B_1)\} + \\
& (Z_{aa}Z_{bb} - Z_{ab}^2)(C_3 - C_1) + \\
& (Z_{bb}Z_{cc} - Z_{bc}^2)(A_1 - A_2 - Z_{aa}) + \\
& (Z_{cc}Z_{aa} - Z_{ca}^2)(B_2 - B_3) + \\
& (Z_{ab}Z_{bc} - Z_{bb}Z_{ca})(A_3 - A_1 + C_1 - C_2 - Z_{ac}) + \\
& (Z_{bc}Z_{ca} - Z_{cc}Z_{ab})(A_2 - A_3 + B_1 - B_2 - Z_{ab}) + \\
& (Z_{ca}Z_{ab} - Z_{aa}Z_{bc})(B_3 - B_1 + C_2 - C_3)
\end{aligned} \quad (9)$$

$$\begin{aligned}
\Delta I_1 = {} & (Z_{aa} + Z_{ab} + Z_{ac})\{K_2(C_3 - C_2) - K_3(B_3 - B_2)\} + \\
& (Z_{bb} + Z_{bc} + Z_{ba})\{K_3(A_3 - A_2) - K_1(C_3 - C_2)\} + \\
& (Z_{cc} + Z_{ca} + Z_{cb})\{K_1(B_3 - B_2) - K_2(A_3 - A_2)\} + \\
& K_1(Z_{bb}Z_{cc} - Z_{bc}^2) - K_3(Z_{aa}Z_{bb} - Z_{ab}^2) + (K_3 - K_1)(Z_{ab}Z_{bc} - Z_{bb}Z_{ca}) + \\
& K_2\{(Z_{ac}Z_{cb} - Z_{cc}Z_{ab}) - (Z_{ac}Z_{ab} - Z_{aa}Z_{cb})\}
\end{aligned} \quad (10)$$

$$\begin{aligned}
\Delta I_2 = {} & (Z_{aa} + Z_{ab} + Z_{ac})\{K_3(B_3 - B_1) - K_2(C_3 - C_1)\} + \\
& (Z_{bb} + Z_{bc} + Z_{ba})\{K_1(C_3 - C_1) - K_3(A_3 - A_1)\} + \\
& (Z_{cc} + Z_{ca} + Z_{cb})\{K_2(A_3 - A_1) - K_1(B_3 - B_1)\} + \\
& K_2(Z_{aa}Z_{cc} - Z_{ca}^2) - K_1(Z_{bb}Z_{cc} - Z_{bc}^2) + \\
& (K_1 - K_2)(Z_{ac}Z_{cb} - Z_{cc}Z_{ab}) + \\
& K_3\{(Z_{ab}Z_{ac} - Z_{aa}Z_{bc}) - (Z_{ab}Z_{bc} - Z_{bb}Z_{ac})\}
\end{aligned} \quad (11)$$

$$\begin{aligned}
\Delta I_3 = {} & (Z_{aa} + Z_{ab} + Z_{ac})\{K_2(C_2 - C_1) - K_3(B_2 - B_1)\} + \\
& (Z_{bb} + Z_{bc} + Z_{ba})\{K_3(A_2 - A_1) - K_1(C_2 - C_1)\} + \\
& (Z_{cc} + Z_{ca} + Z_{cb})\{K_1(B_2 - B_1) - K_2(A_2 - A_1)\} + \\
& K_3(Z_{aa}Z_{bb} - Z_{ab}^2) - K_2(Z_{aa}Z_{cc} - Z_{ac}^2) + (K_2 - K_3) \times (Z_{ba}Z_{ac} - Z_{aa}Z_{bc}) + \\
& K_1\{(Z_{ba}Z_{cb} - Z_{bb}Z_{ca}) - (Z_{ca}Z_{bc} - Z_{cc}Z_{ba})\}
\end{aligned} \quad (12)$$

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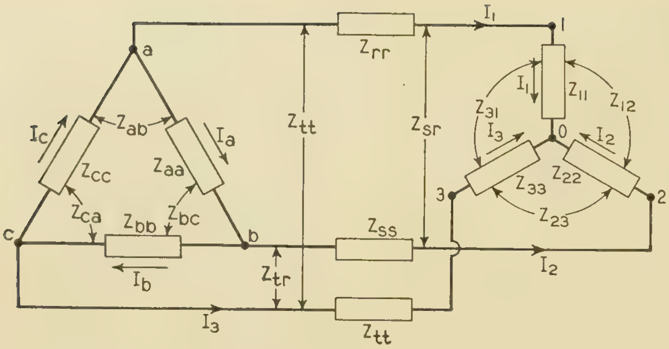

Fig. 1. General circuit Y-Δ connection

$$\begin{aligned}\Delta I_a = {} & K_1\{-(Z_{bb}Z_{cc} - Z_{cb}^2) + Z_{cc}(B_2 - B_3) + \\ & Z_{bc}(C_3 - C_2 + B_1 - B_3) + Z_{bb}(C_3 - C_1) - \\ & (B_2C_3 - B_3C_2) + (B_1C_3 - B_3C_1) - (B_1C_2 - B_2C_1)\} + \\ & K_2\{-(Z_{cb}Z_{ac} - Z_{cc}Z_{ba}), + Z_{cc}(A_3 - A_2) + \\ & Z_{cb}(A_3 - A_1) + Z_{ab}(C_1 - C_3) + Z_{ac}(C_2 - C_3) + \\ & (A_2C_3 - A_3C_2) - (A_1C_3 - A_3C_1) + (A_1C_2 - A_2C_1)\} + \\ & K_3\{-(Z_{ba}Z_{cb} - Z_{bb}Z_{ac}) + Z_{bb}(A_1 - A_3) + \\ & Z_{ab}(B_3 - B_1) + Z_{ac}(B_3 - B_2) + Z_{bc}(A_2 - A_3) - \\ & (A_2B_3 - A_3B_2) + (A_1B_3 - A_3B_1) - (A_1B_2 - A_2B_1)\}\end{aligned} \tag{13}$$

$$\begin{aligned}\Delta I_b = {} & K_1\{-(Z_{ca}Z_{bc} - Z_{cc}Z_{ab}) + Z_{cc}(B_2 - B_1) + \\ & Z_{ba}(C_1 - C_3) + Z_{ca}(B_3 - B_1) + Z_{bc}(C_1 - C_2) - \\ & (B_2C_3 - B_3C_2) + (B_1C_3 - B_3C_1) - (B_1C_2 - B_2C_1)\} + \\ & K_2\{-(Z_{aa}Z_{cc} - Z_{ac}^2) + Z_{aa}(C_3 - C_1) + \\ & Z_{ca}(A_1 - A_3 + C_2 - C_1) + Z_{cc}(A_1 - A_2) + \\ & (A_2C_3 - A_3C_2) - (A_1C_3 - A_3C_1) + (A_1C_2 - A_2C_1)\} + \\ & K_3\{-(Z_{ba}Z_{ac} - Z_{aa}Z_{bc}) + Z_{aa}(B_1 - B_3) + \\ & Z_{ba}(A_3 - A_1) + Z_{ac}(B_1 - B_2) + Z_{bc}(A_2 - A_1) - \\ & (A_2B_3 - A_3B_2) + (A_1B_3 - A_3B_1) - (A_1B_2 - A_2B_1)\}\end{aligned} \tag{14}$$

$$\begin{aligned}\Delta I_c = {} & K_1\{-(Z_{ba}Z_{cb} - Z_{bb}Z_{ca}) + Z(_{bb}C_2 - C_1) + \\ & Z_{ba}(C_2 - C_3) + Z_{ca}(B_3 - B_2) + Z_{cb}(B_1 - B_2) - \\ & (B_2C_3 - B_3C_2) + (B_1C_3 - B_3C_1) - (B_1C_2 - B_2C_1)\} + \\ & K_2\{-(Z_{ca}Z_{ab} - Z_{aa}Z_{cb}) + Z_{aa}(C_3 - C_2) + \\ & Z_{ca}(A_2 - A_3) + Z_{ab}(C_1 - C_2) + Z_{cb}(A_2 - A_1) + \\ & (A_2C_3 - A_3C_2) - (A_1C_3 - A_3C_1) + (A_1C_2 - A_2C_1)\} + \\ & K_3\{-(Z_{aa}Z_{bb} - Z_{ab}^2) + Z_{aa}(B_2 - B_3) + \\ & Z_{ba}(A_3 - A_2 + B_2 - B_1) + Z_{bb}(A_1 - A_2) - \\ & (A_2B_3 - A_3B_2) + (A_1B_3 - A_3B_1) - (A_1B_2 - A_2B_1)\}\end{aligned} \tag{15}$$

The Δ-Y connection contains passive impedance elements and sinusoidal electromotive forces of the same frequency only. This means that if any one self-impedance be varied all voltages and currents will follow circular loci according to the following theorem:[3]

In a network consisting of any number of linear and bilateral self- and mutual-impedance elements connected in any manner with constant sinusoidal electromotive forces of like frequency connected in any arms, all currents and voltages existing in the system follow circular loci when any one self-impedance is varied along a straight line in the complex plane.

If any numerator and the denominator of the phase currents be expanded term by term it will be seen that self-impedances occur only to the first power. Then if any self-impedance be chosen as the variable, the terms of the denominator Δ, may be collected into 2 parts γ the summation of the terms free of the variable, and δ, the summation of the terms containing the variable as a factor. The denominator may then be written as

$$\Delta = \gamma + \delta\rho$$

in which ρ is the scalar variable ranging from zero to infinity as the variable self-impedance varies from short circuit to open circuit.

In the same way, the numerator of any current, such as ΔI_a may be divided into 2 sets of terms, the first α being the summation of terms free of the variable and the second, β, being the summation of terms multiplied by the variable. The numerator may then be expressed as

$$\Delta I_a = \alpha + \beta\rho$$

The current I_a then becomes

$$I_a = \frac{\alpha + \beta\rho}{\gamma + \delta\rho}$$

which is the canonical form of a circular locus expressed as a linear fractional transformation. That is, the vector I_a describes a circle as ρ varies from minus to plus infinity.

The theorem also states that all voltages follow circular loci when any one self-impedance is varied. That this is true may be readily shown by mere inspection of any current equation. The numerator of any current equation is free of all impedance elements through which the current flows. Therefore the product of any current and impedance to obtain a potential difference between 2 points will remain linear with respect to all self-impedances.

To illustrate this condition, the voltage V_{01} across phase 1 of the load will be considered. This voltage is

$$V_{01} = E_{01} + I_1Z_{11} + I_2Z_{12} + I_3Z_{13}$$

$$= \frac{\Delta \times E_{01} + \Delta I_1Z_{11} + \Delta I_2Z_{12} + \Delta I_3Z_{13}}{\Delta}$$

The numerator may be separated into a constant portion α', which is free of the variable and a group of remaining terms β', having ρ as a factor.
Then

$$V_{01} = \frac{\alpha' + \beta'\rho}{\gamma + \delta\rho}$$

Thus the voltage V_{01} follows a circular locus.

The equations are not linear with respect to mutual impedances and on this account the variation of self-impedances must not change any of the mutual elements in the circuit. The 3-point method is used to determine the loci, that is, evaluation of the desired quantity at the 2 invariant points, $\rho = 0$ and $\rho = \infty$, and some third convenient value of ρ. Only the current equations are used in analyti-

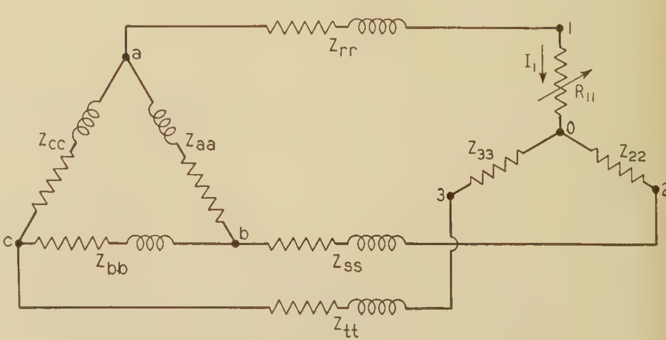

Fig. 2. Circuit for example

al form and once these are reduced to numerical form as near fractional transformations, all voltage loci may be omputed directly therefrom by operating on the currents ith impedances. Inasmuch as the denominator of all urrent and voltage expressions is common, it follows that l summations f currents and oltages remain the form of near fractional transformations. Hence ne loci of all ymmetrical omponents are lso circular.

It is not anticipated that a ractical probm will involve s many unbalnced elements s have been eated in this ircuit. However problems rise in which ny one section f the circuit ay be heavily unbalanced, as for example, single-phase ads. Substitution of such conditions into the equations mplifies them considerably, especially when mutual elenents are absent.

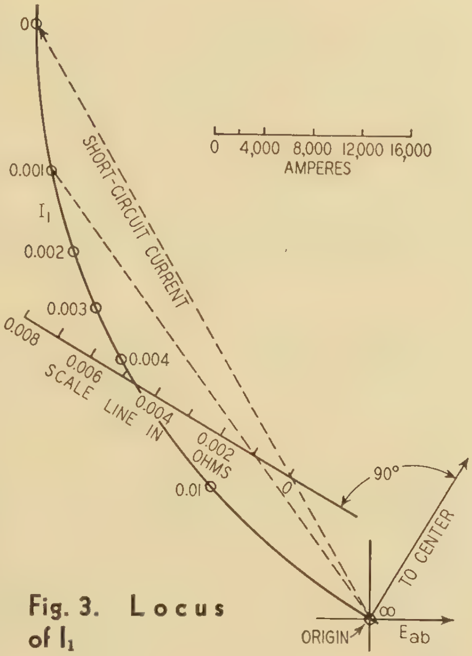

Fig. 3. Locus of I_1

Numerical Example

The circuit drawn in figure 2 will show the application f this method to an actual problem. The source phases re assumed to be balanced with respect to both internal oltages and impedances. No mutual impedances are resent in the source phases. The connecting lines have qual resistances but unequal reactances. The load is ntirely resistive, 2 arms being equal and the third will be onsidered as the variable self-impedance. The loci of the urrent in the variable load phase Z_{11} and the voltage cross it will be determined as the variable R_{11} varies from hort circuit to open circuit. The constants of the circuit re as follows:

$_{aa} = Z_{bb} = Z_{cc} = (0.404 + j2.02)10^{-3}$ ohms
$_{rr} = (0.08 + j1.131)10^{-3}$ ohms
$_{ss} = (0.08 + j0.98)10^{-3}$ ohms $\quad Z_{33} = (5.88)10^{-3}$ ohms
$_{tt} = (0.08 + j0.754)10^{-3}$ ohms $\quad Z_{ab} = Z_{bc} = Z_{ca} = 0$
$_{rs} = (j0.452)10^{-3}$ ohms $\quad Z_{12} = Z_{23} = Z_{31} = 0$ ohms
$_{st} = (j0.415)10^{-3}$ ohms $\quad E_{21} = E_{32} = E_{13} = 0$ volts
$_{tr} = (j0.528)10^{-3}$ ohms $\quad E_{ab} = 230\angle 0°$ volts
$_{11} = R_{11} + j0$ ohms $\quad E_{bc} = 230\angle -120°$ volts
$_{12} = (5.88)10^{-3}$ ohms $\quad E_{ca} = 230\angle 120°$ volts

Substituting in equations (7) the group constants are:

$_1 = (-0.08 - j0.679)10^{-3} - R_{11} \quad A_3 = (0 - j0.113)10^{-3}$

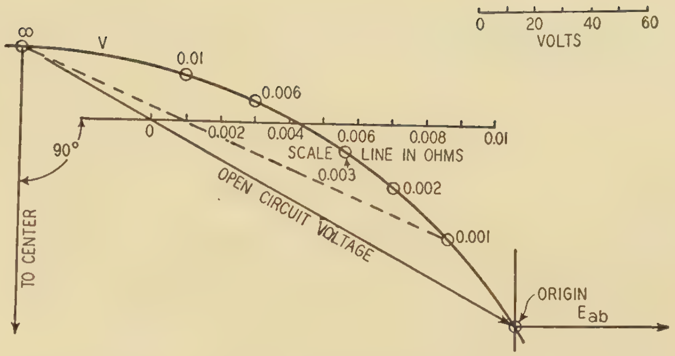

Fig. 4. Locus of V_{01}

$B_2 = (-5.96 - j0.565)10^{-3} \quad B_1 = (0 + j0.076)10^{-3}$
$C_3 = (-5.96 - j0.226)10^{-3} \quad C_2 = (0 + j0.037)10^{-3}$

$A_2 = (5.96 + j0.528)10^{-3} \quad K_1 = 230 + j0$
$B_3 = (5.96 + j0.339)10^{-3} \quad K_2 = -115 - j199.2$
$C_1 = (0.08 + j0.603)10^{-3} \quad K_3 = -115 + j199.2$

From equation (9) the denominator becomes

$\Delta = (0.134 - j0.252)10^{-6} + R_{11}\,(-1.14 - j76.6)10^{-6}$

From equation (10) the numerator of I_1 is

$\Delta I_1 = (8000 + j13300)10^{-6}$

The current I_1 written as a linear fractional transformation is then

$$I_1 = \frac{8000 + j13300}{(0.134 - j0.252) + R_{11}(-1.14 - j76.6)}$$

Determining the invariant points and using $R_{11} = 0.001$ ohm for the third point the corresponding currents are:

R_{11} ohms	I_1 amperes
0	54400 $\angle 121.0°$
0.001	44800 $\angle 126.9°$
∞	0

These 3 points determine the locus of I_1 which is drawn in figure 3.

The voltage V_{01} across phase 1 of the load is

$$V_{01} = I_1 Z_{11} = \frac{R_{11}(8000 + j13300)}{(0.134 - j0.252) + R_{11}(-1.14 - j76.6)}$$

Evaluating V_{01} at the same 3 points gives:

R_{11} ohms	V_{01} volts
0	0
0.001	44.8 $\angle 126.9°$
∞	205 $\angle 149.8°$

These points determine the locus of V_{01} which is plotted in figure 4.

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Intersheet Eddy-Current Loss in Laminated Cores

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CORE LOSS in laminated structures subjected to an alternating magnetomotive force is made up of a hysteresis loss and an eddy-current loss. In modern power transformers the eddy-current loss is approximately $^1/_4$ to $^1/_3$ of the total loss.

In the calculation of the eddy-current loss it is usually tacitly assumed that the parasitic currents are confined to the individual laminations, and that there is no appreciable cross flow from sheet to sheet. Further, it is assumed for the purposes of calculation that the current flow in the individual laminations is everywhere parallel to the width of the laminations, and the end effects are ignored; and usually, also, the demagnetizing effect is not taken into account.

While those assumptions have always appeared to be fully justified for engineering purposes; nevertheless, the validity of the assumption that the intersheet eddy-current losses are negligible is often questioned. For it is evident that as the width of the laminations is increased, the resistance across the packet decreases, whereas the flux increases; and it may very well be, therefore, that the intersheet loss is appreciable for large cores; particularly in those cases where the clamping pressure is very high, because the resistance rapidly decreases with the pressure.

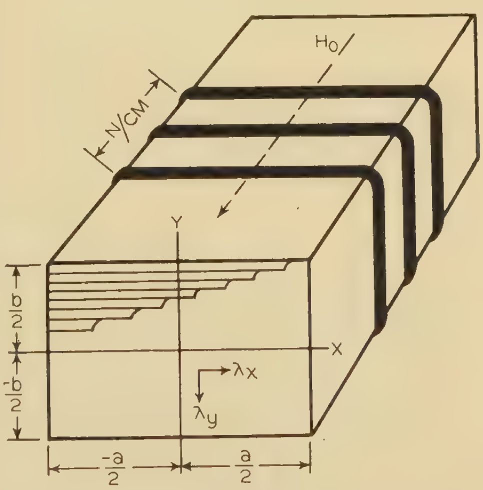

Fig. 1. Cross section of rectangular core

The investigation described herein was undertaken to determine the magnitude of the intersheet eddy-current loss, and incidentally to obtain a more rigorous formula for the eddy currents in rectangular sections that gives the actual distribution. While such refinements are found to be quite unnecessary as far as transformers are concerned, yet they may prove useful in other applications, particularly in cases where the punchings are not enamel insulated and immersed in insulating oil. Moreover, the results for the case where the ratio of conductivities is equal to unity apply exactly to a solid rectangular block, and also indicate the true end-effect correction in laminations even in the case of perfectly insulated punchings of finite thickness.

The cross section of a rectangular core is shown in figure 1. Uniform conductivities λ_x and λ_y along and across the sheets are assumed. For definiteness, the core is considered as placed inside a long solenoid with NI ampere-turns per centimeter length, so that the field perpendicular to the core section is given by

$$H_0 = 0.4\pi NI \tag{1}$$

For the purposes of analysis, co-ordinates (x, y) are chosen with origin at the center of the core. The mathematical derivations are given in the appendix, and are briefly as follows:

a. From Maxwell's equations there are obtained the differential equations for the field intensity H, and the relationship between H and the electric intensity E.

b. The solution of the differential equation, subject to the boundary condition $H = H_0$ around the periphery of the core is obtained. The process of solution is the conventional method of product solutions and sums of these that satisfy the boundary conditions (see, for example, chapter IV of Byerly's "Fourier Series and Spherical Harmonics").

c. The flux ϕ is readily found by integrating H. Using the usual representation of sinusoidal quantities by complex numbers, the flux ϕ is given by either of the formulas:

$$\frac{\phi}{\phi_0} = \frac{\tanh\,[(\alpha a)/(2\sqrt{r})]}{(\alpha a)/(2\sqrt{r})} + \frac{8}{\pi^2}\sum_{1,3,\ldots}^{\infty}{}_n \frac{1}{n^2}\left(\frac{\alpha}{\beta_n}\right)^2 \frac{\tanh(\beta_n b/2)}{(\beta_n b/2)} \tag{2}$$

$$\frac{\phi}{\phi_0} = \frac{8}{\pi^2}\sum_{1,3,\ldots}^{\infty}{}_n \frac{1}{n^2}\left\{\frac{\tanh\,(\alpha_n a/2)}{(\alpha_n a/2)} + \frac{\tanh\,(\beta_n b/2)}{(\beta_n b/2)}\right\} \tag{3}$$

where

ϕ_0 = flux corresponding to the maximum (crest value) of H_0 or the applied current I

$$\alpha_n^2 = \left(\alpha^2 + \frac{n^2\pi^2}{b^2}\right)\frac{1}{r} \qquad \beta_n^2 = \left(\alpha^2 + r\,\frac{n^2\pi^2}{a^2}\right)$$

$\alpha^2 = j\omega 4\pi\lambda_x\mu 10^{-9}$
$\omega = 2\pi f$
λ_x = conductivity along laminations
λ_y = conductivity across laminations
$r = \lambda_x/\lambda_y$ = ratio of conductivities
μ = permeability of the iron (assumed constant)
a, b = core dimensions

d. The induced electromotive force in the winding is given by

$$E = -j\omega N\phi 10^{-8} \tag{4}$$

where N is the number of terms.

The loss W may be found from the real part of E, which

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in phase with the exciting current, and turns out to be ven by

$$= \frac{\omega \phi_0 H_0}{8 \times 10^7} [- \mathfrak{I} (\phi/\phi_0)] \text{ watts per centimeter} \quad (5)$$

which

= the maximum (crest value) of the current and $\mathfrak{I}(x + jy) = y =$ imaginary part of the complex number $(x + jy)$

For large values of r ($>$ 1,000) the formula (2) may be placed by its first term:

$$\simeq \frac{\tanh [(\alpha a)/(2\sqrt{r})]}{(\alpha a)/(2\sqrt{r})} \quad (6)$$

his identical result is obtained if the currents are assumed flow straight across the laminations and the end effects e neglected.

For small values of $[(\alpha a)/(2\sqrt{r})]$, (5) may be replaced

$$= \frac{\lambda_y}{24} \left(\frac{\omega \phi_0}{10^8}\right)^2 \frac{a}{b} \text{ watts per centimeter} \quad (7)$$

his latter expression is also obtained if the currents are sumed to flow across the laminations and their de-agnetizing effect be neglected.

The calculation of the losses by (5) or (6) is seen to nge on the evaluation of complex functions of the form

$$\frac{\text{nh}\ (p + jq)}{(p + jq)} = U + jV$$

n account of the great differences between the con-ictivities λ_x and λ_y (their ratio may be as great as 10^7:1), eat care must be taken in evaluating these functions order to secure sufficient accuracy. Methods are given the appendix.

Direct calculations of the losses by integration through-it the core section is possible, but proves to be quite volved. The application of Poynting's vector, how-er, leads to the same result for the losses with only ightly more labor than the total flux method.

ppendix

Maxwell's equations in centimeter-gram-second practical units are

$$\times H = 0.4\pi i \quad (8)$$

$$\times E = -10^{-8} \frac{\partial B}{\partial t} \quad (9)$$

ere H is the magnetic field, E the dielectric field (volts per centi-eter), i the current density vector, and B the flux density. Re-ace B by μH, and assume the time t to enter as a factor $\epsilon^{j\omega t}$ (but nit this factor in subsequent equations). Then supposing the ly nonvanishing component of the magnetic field to be H_z the com-nent along the solenoid axis, while the induced field and current mponents are perpendicular to the z axis; and finally that the ld aspect is independent of z, there follows from (8) and (9)

$$\frac{H}{\ } = 0.4\pi i_x, \qquad \frac{\partial H}{\partial x} = -0.4\pi i_y \quad (10)$$

$$\frac{E_y}{\ } - \frac{\partial E_x}{\partial y} = -j\omega\mu 10^{-8} H \quad (11)$$

e subscript in H_z having been omitted since this is the only com-nent present and there can be no confusion. Since the conductivities λ_x and λ_y are different in the 2 orthogonal directions, there is (neglecting the displacement currents)

$$i_x = \lambda_x E_x, \qquad i_y = \lambda_y E_y \quad (12)$$

Eliminating i_x, i_y, E_x, E_y there is by (10), (11), and (12)

$$\frac{\lambda_x}{\lambda_y} \frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2} = j\omega 4\pi\lambda_x\mu 10^{-9} H \quad (13)$$

or putting $r = \lambda_x/\lambda_y$ and $\alpha^2 = j\omega 4\pi\lambda_x\mu 10^{-9}$

$$r \frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2} = \alpha^2 H \quad (13a)$$

It is of interest to point out that the relations of the form (12) exist in crystalline media which are homogeneous but not isotropic, though in the general case the 3 current components are expressible linearly in each of the field components by means of 9 conductivity constants, and similarly for the relation between the magnetic field and flux components.

Returning to the differential equation 13a, which is the differential equation of the problem, a solution H is sought which takes on the boundary conditions

$$H = H_0 \text{ along } x = \pm a/2 \text{ and } y = \pm b/2 \quad (14)$$

where H_0 is given by (1).

To satisfy the boundary conditions (14) we may try to satisfy them first along 2 opposite sides of the rectangular boundary. A solution of (13a) independent of y and which satisfies the boundary condition (14) along $x = \pm a/2$ is

$$H_1 = H_0 \frac{\cosh \alpha' x}{\cosh \alpha' a/2}, \quad \alpha' = \frac{\alpha}{\sqrt{r}} \quad (15)$$

Writing the complete solution

$$H = H_1 + H_2 \quad (16)$$

it remains to find H_2 such that

$$H_2 = 0 \text{ along } x = \pm a/2 \quad (17)$$

$$H_2 + H_1 = H_0 \text{ along } y = \pm b/2 \quad (18)$$

Product solutions of (13a) of the form

$$\cos \frac{n\pi x}{a} \cosh \beta_n y, \qquad \beta_n{}^2 = \alpha^2 + \frac{rn^2\pi^2}{a^2}$$

for $n = 1, 3, \ldots$ satisfy (17). To satisfy (18), or more explicitly

$$H_2 = H_0 \left(1 - \frac{\cosh \alpha' x}{\cosh \alpha' a/2}\right) \text{ along } y = \pm \frac{b}{2} \quad (18a)$$

an infinite series of the product solutions will be used:

$$H_2 = H_0 \sum_{1,3,\ldots}^{n} C_n \cos \frac{n\pi x}{a} \cosh \beta_n y \quad (19)$$

To satisfy (18a) the constants C_n must be chosen so that

$$\sum C_n \cosh \frac{\beta_n b}{2} \cos \frac{n\pi x}{a} = 1 - \frac{\cosh \alpha' x}{\cosh \alpha' a/2} = f(x) \quad (20)$$

By Fourier's theorem, an arbitrary even function $f(x)$ in the interval $(-a/2, a/2)$ can be expanded in a series

$$\sum_{1,3,\ldots}^{n} A_n \cos \frac{n\pi x}{a}$$

and the series converges to $f(x)$ at $x = \pm a/2$ only if $f(x)$ vanishes there—this is the case at present. Applying the familiar rule for the Fourier coefficients to (20), there follows:

$$C_n \cosh \frac{\beta_n b}{2} = \frac{2}{a} \int_{-a/2}^{a/2} \left(1 - \frac{\cosh \alpha' x}{\cosh \alpha' a/2}\right) \cos \frac{n\pi x}{a}\, dx \quad (21)$$

To evaluate this integral, write it in the from

$$\int fg''dx$$

where primes denote differentiations, and integrate by parts twice, obtaining

$$\int fg''dx = \int f''gdx + [fg' - f'g] = \int f''gdx$$

since at the end points both

$$f = \left(1 - \frac{\cosh \alpha' x}{\cosh \alpha' a/2}\right) \text{ and } g = \frac{-a^2}{n^2\pi^2} \cos \frac{n\pi x}{a}$$

vanish in the present case. Also $f'' = (\alpha')^2(f - 1)$ while $g = -(a^2/n^2\pi^2)\, g''$, hence

$$\int fg''dx = -\frac{\alpha'^2 a^2}{n^2\pi^2} \int fg''dx - \alpha'^2 \int gdx$$

or

$$\int fg''dx = \frac{-\alpha'^2}{1 + \alpha'^2 a^2/n^2\pi^2} \int gdx$$

Carrying out the latter integration, solving for C_n and substituting in (19), (16) there follows:

$$\frac{H}{H_0} = \frac{\cosh \alpha' x}{\cosh \alpha' a/2} + \frac{4}{\pi} \sum_{1,3,\ldots}^{n} \frac{\sin n\pi/2}{n} \left(\frac{\alpha}{\beta_n}\right)^2 \frac{\cosh \beta_n y}{\cosh \beta_n b/2} \cos \frac{n\pi x}{a} \tag{22}$$

From this, (2) is derived by integration.

Another form for H is offered by

$$\frac{H}{H_0} = \frac{4}{\pi} \sum_{1,3,\ldots}^{n} \frac{\sin n\pi/2}{n} \left\{ \frac{\cosh \alpha_n x}{\cosh \alpha_n a/2} \cos \frac{n\pi y}{b} + \frac{\cosh \beta_n y}{\cosh \beta_n b/2} \cos \frac{n\pi x}{a} \right\} \tag{23}$$

where

$$\alpha_n^2 = \left(a^2 + \frac{n^2\pi^2}{b^2}\right) \frac{1}{r}$$

This is obtained by breaking up H into 2 parts, of which one satisfies the boundary conditions (14) along $x = \pm a/2$ and vanishes along $y = \pm b/2$, while the other one satisfies (14) along $y = \pm b/2$ and vanishes along $x = \pm a/2$, and then solving for each one by means of an infinite series of product solutions and Fourier's theorem. From (23) the flux (3) follows by integration.

As compared with (22), the form (23), while more symmetric, involves 2 infinite series and has poorer convergence. This is due to the fact that the former Fourier expansion was for a function that vanished at the end points, while such is not the case for the expansions in (23).

From (2), (3), (5) it is seen that the calculation of the losses hinges on the functions of the form

$$U + jV = \frac{\tanh\ (p + jq)}{(p + jq)} \tag{24}$$

But it is only the imaginary component, V, of this function which contributes to the loss. In the laminated core problem, it so happens, on account of the great differences in conductivity along and perpendicular to the laminations, that either p is very large, or else p and q are small and very nearly alike. For these 2 cases we have:

Case I

Suppose p is very large (say of the order of 100). Then

$$U + jV = \frac{\tanh\ (p + jq)}{(p + jq)} = \frac{\tanh p + j \tan q}{1 + j \tanh p \tan q} \frac{1}{p + jq}$$

$$\cong \frac{1}{p + jq} = \frac{p}{p^2 + q^2} - j\frac{q}{p^2 + q^2} \cong \frac{1}{p} - j\frac{q}{p^2} \tag{25}$$

Case II

Suppose both p and q small compared to unity. Then

$$U + jV = \frac{\tanh\ (p + jq)}{p + jq} = 1 - \frac{1}{3}(p + jq)^2 + \frac{2}{15}(p + jq)^4 + \ldots \cong \left(1 - \frac{p^2 - q^2}{3}\right) - j\frac{2}{3}pq \tag{26}$$

Approximations

In the differential equation (13*a*) the ratio λ_x/λ_y may be of the order of 10^7 and the term $\partial^2 H/\partial y^2$ may then be dropped, so that (13*a*) becomes

$$\frac{\partial^2 H}{\partial x^2} = \frac{\alpha^2}{r} H = \alpha'^2 H \tag{27}$$

subject to the boundary condition $H = H_0$ at $x = \pm a/2$. The solution therefore is

$$H = H_0 \frac{\cosh \alpha' x}{\cosh \alpha' a/2} \tag{28}$$

which is the first term of (22). The flux becomes

$$\frac{\phi}{\phi_0} = \frac{\tanh \alpha' a/2}{\alpha' a/2} \tag{29}$$

which will be recognized as (6). As pointed out above, this is also obtained from (2) due to the smallness of the series. The losses are given by

$$W = \mathbf{I}\left[\frac{\omega\phi H_0}{8\pi 10^8} \frac{\tanh \alpha' a/2}{\alpha' a/2}\right] \tag{30}$$

If the demagnetizing effect of the eddy currents is negligible, on the right-hand side of (27) put

$$\frac{\partial^2 H}{\partial x^2} = \alpha'^2 H_0 \tag{31}$$

the solution to which is

$$\frac{H}{H_0} = \left[1 - j\frac{4\pi\mu\omega\lambda_y}{10^9}\left(\frac{a^2}{8} - \frac{x^2}{2}\right)\right] \tag{32}$$

The flux is

$$\frac{\phi}{\phi_0} = \left(1 - j\frac{\pi\mu\omega\lambda_y a^2}{3 \times 10^9}\right) \tag{33}$$

and the losses become

$$W = \frac{\lambda_y}{24}\left(\frac{\omega\phi_0}{10^8}\right)^2 \frac{a}{b} \tag{34}$$

This approximation is the exact equivalent of assuming the eddy current to flow straight across the laminations parallel to the Y axis, and neglecting the demagnetizing effect. Thus on these assumptions, the flux included between $-x$ and $+x$ is

$$\phi = 2\, b\mu H_0 x \tag{35}$$

which induces the voltage

$$e = -j\frac{2\omega}{10^8} \mu H_0 bx \tag{36}$$

The resistance of the elementary path is

$$\frac{2b}{\lambda_y\, dx} \tag{37}$$

and the losses therefore are ($e_{\mathrm{rms}} = e/\sqrt{2}$)

$$W = \frac{\lambda_y}{2b}\int_0^{a/2} e^2 dx = \frac{\lambda_y}{24}\left(\frac{\omega a b\mu H_0}{10^8}\right)^2 \frac{a}{b}$$

$$= \frac{\lambda_y}{24}\left(\frac{\omega\, \phi_0}{10^8}\right)^2 \frac{a}{b} \tag{38}$$

Some Series Formulas for Mutual Inductance of Solenoids

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ABSOLUTE formulas for the mutual inductance of coaxial solenoids have been derived by Nagaoka, Terezawa, and Olshausen. These all give the ıtual inductance as a combination of 4 integrals—2 sitive and 2 negative—each of which is a function of e of the 4 distances measured between an end of one lenoid and an end of the other. The expressions for ese terms involve elliptic integrals of all 3 kinds, and ımerical computations of their values are exacting.

Fortunately, it is possible to use in place of the absolute rmulas series expansions of them involving ratios of e dimensions of the coils. However, on account of the ımber of parameters involved, no single series exnsion will suffice for all possible pairs of coils.

The present paper has for its object the derivation of w series formulas suitable for cases not previously vered. A survey is also made of the whole field.

The new formulas here developed are derived from rtain basic formulas included in the Bureau of Standds collection of inductance formulas.[2] For the conınience of the reader, there have been here reproduced om that collection, in an appendix, those expressions which reference will be made. The formula numbers the original are retained in the appendix with the ter A added, in order to avoid confusion with the rmula numbers of the present paper.

Formulas for the mutual inductance of solenoids are ıally obtained by integrating expressions for the mutual ductance of circles. For circles comparatively near gether, a very useful formula (16)A has been given by H. Havelock,[1] which has been extended by E. B. Rosa d F. W. Grover.[2] As the latter authors say in comring it with their equation (14)A, which is an extension a formula given by Clerk Maxwell, equation (16)A reires only half as many terms to be calculated for a ven degree of convergence. Another fundamental rmula (56)A for mutual inductance of a solenoid and coaxial circle was given by Rosa, Scientific Paper 169, ge 101.

In this paper, the formulas (16)A and (56)A, menned above, will be used to derive some formulas for enoids, and their ranges of application will be invesated by means of numerical examples.

The mutual inductance of 2 coaxial but unequal solenoids which are not far apart, can be obtained by twice integrating the equation (16)A, first over the length of one solenoid and second over the length of the other. See figure 1. The result is as follows:

$$\frac{M}{n_1n_2} = F_{(x1)} - F_{(x2)} - F_{(x3)} + F_{(x4)} \text{ abhenries} \tag{1}$$

where n_1 and n_2 are the turns per centimeter of the coils, respectively, and where

$$x_1 = s + m_1 + m_2 \tag{2}$$

$$x_2 = s + m_1 - m_2 \tag{3}$$

$$x_3 = s - m_1 + m_2 \tag{4}$$

$$x_4 = s - m_1 - m_2 \tag{5}$$

$$\begin{aligned}F_{(x)} = \frac{\pi d^2\sqrt{Dd}}{2}\Bigg[&\left\{\text{logn}\,\frac{x^2+c^2}{c^2}\right\}\times \left\{\frac{c^2}{d^2}\left(1+\frac{3}{8}\frac{c^2}{Dd}-\frac{5}{64}\frac{c^4}{D^2d^2}+\frac{35}{1024}\frac{c^6}{D^3d^3}\right)\right\}+\\ &\left\{\text{logn}\,\frac{16Dd}{x^2+c^2}\right\}\left\{\frac{x^2}{d^2}\left(1+\frac{3}{4}\frac{c^2}{Dd}-\frac{15}{64}\frac{c^4}{D^2d^2}+\frac{35}{256}\frac{c^6}{D^3d^3}\right)+\right.\\ &\frac{x^4}{8Dd^3}\left(1-\frac{5}{8}\frac{c^2}{Dd}+\frac{35}{64}\frac{c^4}{D^2d^2}\right)-\\ &\left.\frac{x^6}{64D^2d^4}\left(1-\frac{7}{4}\frac{c^2}{Dd}\right)+\frac{5}{1024}\frac{x^8}{D^3d^5}\ \cdots\right\}-\\ &\frac{4cx}{d^2}\left\{\tan^{-1}\frac{x}{c}\right\}\left\{1+\frac{c^2}{2Dd}-\frac{c^4}{8D^2d^2}+\frac{c^6}{16D^3d^3}\right\}-\\ &\frac{x^2}{d^2}\left(1-\frac{9}{8}\frac{c^2}{Dd}-\frac{1}{16}\frac{c^4}{D^2d^2}+\frac{325}{3072}\frac{c^6}{D^3d^3}\right)+\\ &\frac{x^4}{16Dd^3}\left(1+\frac{3}{2}\frac{c^2}{Dd}-\frac{695}{384}\frac{c^4}{D^2d^2}\right)+\\ &\frac{x^6}{48D^2d^4}\left(1-\frac{149}{64}\frac{c^2}{Dd}\right)-\frac{109}{12288}\frac{x^8}{D^3d^5}\cdots\Bigg]\end{aligned} \tag{6}$$

where logn denotes natural logarithm.

If x is large, say greater than the radius a, or if c is comparatively large, say greater than $a/2$, the following expression for $F_{(x)}$, obtained by integrating equations (56)A, may be used:

$$\begin{aligned}F_{(x)} = 2\pi^2a^2A\Bigg[&\frac{r}{A}-\frac{a^2A}{8r^3}+\frac{a^4A}{16r^5}-\frac{5}{64}\frac{a^4A^3}{r^7}-\\ &\frac{5}{128}\frac{a^6A}{r^7}+\frac{35}{256}\frac{a^6A^3}{r^9}+\frac{7}{256}\frac{a^8A}{r^9}-\frac{105}{1024}\frac{a^6A^5}{r^{11}}-\\ &\frac{189}{1024}\frac{a^8A^3}{r^{11}}-\frac{21}{1024}\frac{a^{10}A}{r^{11}}+\frac{693}{2048}\frac{a^8A^5}{r^{13}}+\frac{231}{1024}\frac{a^{10}A^3}{r^{13}}+\\ &\frac{33}{2048}\frac{a^{12}A}{r^{13}}-\ \ldots+\left(-1+\frac{a^2}{8A^2}+\frac{a^4}{64A^4}+\frac{5}{1024}\frac{a^6}{A^6}+\right.\\ &\left.\frac{35}{16384}\frac{a^8}{A^8}+\frac{147}{128\times 1024}\frac{a^{10}}{A^{10}}+\ldots\right)\Bigg]\end{aligned} \tag{7}$$

where

$$r^2 = x^2 + A^2 \tag{8}$$

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Phil. Mag., volume 15, 1908, page 332.

FORMULAS AND TABLES FOR THE CALCULATION OF MUTUAL AND SELF-UCTANCE, E. B. Rosa and F. W. Grover. Scientific Paper 169 of the eau of Standards, Washington, D. C. Scientific Paper 169 was published as part number 1 of volume 8 of the *Bulletin* of the Bureau of Standards.

By grouping together terms of (7) of the same power of a, the following alternative form is obtained:

$$F_{(x)} = 2\pi^2 a A^2 \Bigg[C_0 + \frac{a^3}{8r^3} C_2 + \frac{a^5}{64r^5} C_4 + \frac{5}{1024}\frac{a^7}{r^7} C_6 + \frac{35}{16384}\frac{a^9}{r^9} C_8 + \frac{147}{128 \times 1024}\frac{a^{11}}{r^{11}} C_{10} + \ldots + \frac{a}{A}\left(-1 + \frac{a^2}{8A^2} + \frac{a^4}{64A^4} + \frac{5}{1024}\frac{a^6}{A^6} + \frac{35}{16384}\frac{a^8}{A^8} + \frac{147}{128 \times 1024}\frac{a^{10}}{A^{10}} + \ldots\right)\Bigg] \quad (9)$$

where

$$C_0 = \frac{ar}{A^2} = \frac{a\sqrt{(x^2 + A^2)}}{A^2}$$

$$C_2 = -1$$

$$C_4 = 2\left(2 - \frac{5}{2}\frac{A^2}{r^2}\right)$$

$$C_6 = 7\left(-\frac{8}{7} + 4\frac{A^2}{r^2} - 3\frac{A^4}{r^4}\right)$$

$$C_8 = \frac{9}{5}\left(\frac{64}{9} - 48\frac{A^2}{r^2} + 88\frac{A^4}{r^4} - \frac{143}{3}\frac{A^6}{r^6}\right)$$

$$C_{10} = \frac{11}{7}\left(-\frac{128}{11} + 128\frac{A^2}{r^2} - 416\frac{A^4}{r^4} + 520\frac{A^6}{r^6} - 221\frac{A^8}{r^8}\right)$$

Equations (7) and (9) are equivalent to (6) in all respects and they give the same numerical result as (6) for any case to which both the formulas can be properly applied. The criterion as to whether a series is applicable is that the last terms used shall be negligibly small. In other words, the series shall be practically convergent in the number of terms which are used.

Equation (6) is given in terms of diameters and (7) and (9) in terms of radii so that the numerical coefficients in each series will be as small as possible.

It is to be noted that the 4 values of $F_{(x)}$ in (1) need not necessarily be computed all by (6) or all by (7) or by (9), but some can be computed by one expression and some by another. This may be necessary in some cases, for x_1 may be so large that (6) cannot be used, and for the same pair of coils x_4 may be so small that only (6) can be employed.

There is an advantage in using (7) or (9) for all 4 cases of (1), namely, that then the round bracket of (7) or (9) need not be computed, for it is like a constant of integration and would cancel out when the 2 positive and 2 negative values were added.

The round bracket of (7) and (9) was put in for the purpose of making (7) and (9) equivalent to (6). All these expressions have the same physical interpretation—they are $^1/_2$ the mutual inductance of 2 equal and concentric coils of length x and with one turn per centimeter. See equation (11). Thus, (9) is the same, term for term, as the well known mutual-inductance formula (36)A, (Scientific Paper 169, page 53), multiplied by $^1/_2$. A considerable number of additional terms of (7) and (9) can be written down by inspection, from this corresponding formula (36)A. The terms of (7), (9), and (21) are the same as those in the paper "Mechanical Forces in Transformers," by J. E. Clem, AIEE TRANSACTIONS, volume 46, 1927, page 577. The general term of the round bracket of (7) and (9) is given in the paper by T. H. Havelock, reference 1, and on page 56 of Scientific Paper 169. (See appendix also.)

Where a is considerably smaller than A, the grouping in (9) according to powers of a is convenient, but if x and therefore r are relatively large, the grouping according powers of r, as in (7) and (22), is convenient. That is, in general, (7) is for long coils and (9) for short coils, though not as short as those for which (6) is used. However, there is very little difference between (7) and (9) for they contain the same terms and the terms which are not negligible must be computed while those that are negligible will be omitted.

When the 2 coils are concentric as well as coaxial, $s = 0$. It is to be noted that only even powers of x are involved in (6), (7), and (9), and so

$$F_{(x)} = F_{(-x)}$$

Therefore, for concentric coils of unequal length,

$$\frac{M}{n_1 n_2} = 2F_{(m_1+m_2)} - 2F_{(m_1-m_2)} \quad (10)$$

Equation (10), using (6), (7), or (9) as convenient, is thus equivalent to Rôiti's formula, equation (39)A, or Searle and Airey's formula extended, equation (43)A.

A further simplification results when the 2 concentric coils are of equal length, in which case only one expression is required.

$$\frac{M}{n_1 n_2} = 2F_{(2m_1)} \quad (11)$$

For (6), (7), and (9),

$$F_{(0)} = 0 \quad (12)$$

The round bracket of (7) and (9) was inserted to make this so. As previously mentioned, equation (11), using (7) or (9) is the same as equation (36)A. It is equivalent to equation (38) of Scientific Paper 169 or other formulas which are given for this type of problem.

Each dimension of the cross section of a coil should be taken to be the number of wires in a row along that dimension, multiplied by the center-to-center distance between adjacent wires.

If the 2 concentric coils of equal length are shorter than approximately the radius of the inner one, and if c is less than $^1/_2$ the radius, equation (6) used with (11) is appropriate to use. It is a mutual-inductance formula which it is believed has not previously been published. It is very similar to equation (1) of the paper "Mutual Inductance of Short Concentric Solenoids," by H. B. Dwight and P. W. Sayles, *Journal of Mathematics and Physics*, volume 9, 1930, page 162. It is several terms shorter, for the same rapidity of convergence. Equation (6) of this paper contains only even powers of c in the series but equation (1) of the paper referred to contains both odd and even powers of c, which increases the number of terms in the formula without any advantage.

A similar shortening of a formula by using (16)A in-

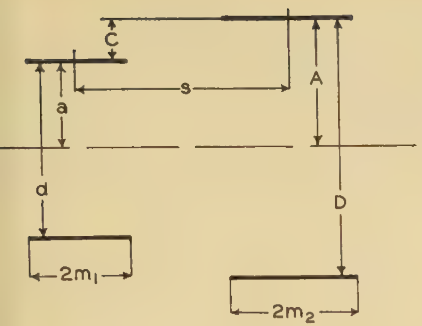

Fig. 1. Two coaxial solenoids

ead of (14)A, may be made in the case of equation 5)A, for the mutual inductance of 2 circles in the same ane. By putting $x = 0$ in (16)A, there results

$$= 4\pi\sqrt{Aa}\left[\left\{\log n\frac{8\sqrt{Aa}}{c}\right\}\left\{1+\frac{3}{16}\frac{c^2}{Aa}-\frac{15}{1024}\frac{c^4}{A^2a^2}+\frac{35}{128^2}\frac{c^6}{A^3a^3}-\frac{1575}{2\times 128^3}\frac{c^8}{A^4a^4}\cdots\right\}-2-\frac{c^2}{16Aa}+\frac{31}{2048}\frac{c^4}{A^2a^2}-\frac{247}{6\times 128^2}\frac{c^6}{A^3a^3}+\frac{7795}{8\times 128^3}\frac{c^8}{A^4a^4}\cdots\right] \quad (13)$$

his contains only even powers of c in the series, and so can said to have $^1/_2$ as many terms as equation (15)A.

Another simplification of the problem of mutual inictance occurs when the 2 coils are not concentric but ave equal radii. This means that $c = 0$ and $A = a$. ormula (6) then becomes $^1/_2$ times a self-inductance rmula, namely, (71)A (page 117, Scientific Paper 69). Formulas (7) and (9) similarly become $^1/_2$ mes the self-inductance formula (11) published in the IEE TRANSACTIONS, volume 38, 1919, page 1688. Equaon (1) of this paper becomes the same as equation (51)A. hen 2 coils have equal radii, their mutual inductance in be calculated by the above-mentioned equation 1)A, using well-known self-inductance formulas, and orrections can be added for the thickness of the winding id for the shape and spacing of the conductors. See cientific Paper 169, pages 140–41.

Equation (51)A can be used also for 2 concentric coils equal length and of appreciable thickness of winding.

It is seen from equations (1) to (5) that if in the dimenons of the lengths, $2m_1$ and $2m_2$ are interchanged, the utual inductance and also the force (see equation 20), e not changed. This can be called the *principle of iterchange of lengths*. It has been pointed out previously r the mutual inductance of concentric solenoids. (See cientific Paper 169, page 68.) Since it applies to each iin cylindrical element of thick solenoids or coils, it pplies to the entire coils.

An inspection of the formulas[3] shows that the principle interchange of lengths applies also to mutual inductance id force of unequal coils with parallel axes.

This principle applies, of course, to the case of a solenoid id coaxial circle also. That is, the mutual inductance a solenoid, of length $2m$ and a radius A, and a circle radius a in its end plane, is the same as the mutual iductance of a solenoid of the same length $2m$ but of radius a, and a coaxial circle of radius A in its end plane.

Equation (51)A is derived from the knowledge of the properties of mutual and self inductance of coils. A corresponding relationship of mutual inductances for equation (1) of this paper is of interest since it makes clear the physical meaning of the formula. It requires the use of the principle of interchange of lengths, which is dependent on (1), and so it is not to be taken as a proof of (1).

Suppose that in addition to the 2 thin solenoids of figure 1, there are 4 others as in figure 2, the turns per centimeter being the same for all coils of a given radius. Since these touch each other end to end, they form longer solenoids. For instance, the 3 solenoids P, Q, and R form one long solenoid which can be called $P+Q+R$.

$$M_{(P+Q+R)(p+q+r)} = M_{Pp} + M_{Pq} + M_{Pr} + M_{Qp} + M_{Qq} + M_{Qr} + M_{Rp} + M_{Rq} + M_{Rr}$$

Using the principle of interchange of lengths, by which $M_{Qp} = M_{Pq}$ etc., this becomes

$$M_{Pp} + M_{Qq} + M_{Rr} + 2M_{Pq} + 2M_{Qr} + 2M_{Rp}$$

Similarly,

$$M_{(P+Q)(p+q)} = M_{Pp} + M_{Qq} + 2M_{Pq}$$

and

$$M_{(Q+R)(q+r)} = M_{Qq} + M_{Rr} + 2M_{Qr}$$

Solving these equations simultaneously in such a way as to leave only pairs of coils which are concentric and of equal length on the right-hand side of the equation,

$$2M_{Rp} = M_{(P+Q+R)(p+q+r)} - M_{(P+Q)(p+q)} - M_{(Q+R)(q+r)} + M_{Qq} \quad (14)$$

The lengths of the concentric coils are evidently x_1, x_2, x_3, and x_4.

In a similar way, equation (10) can be treated.

In the general formula (10) for concentric solenoids the mutual inductance is given by the difference of 2 series. In the formula of Searle and Airey (formula (43)A) a *single* series of terms suffices for its calculation. Searle and Airey's formula may be derived from (10) and (7) by expanding the 2 values of r in powers of the ratios of the solenoid lengths to the diagonal drawn from the center to the end of the longer solenoid and combining terms.

This formula does not converge well when the solenoids are of nearly equal radii and their lengths are small, compared with their radii. In such cases formula (6) must be used in connection with (10).

On the other hand, when the lengths of the coils are large, compared with their radii, the coefficients X_{2n} and L_{2n} may become very large, rendering the use of this

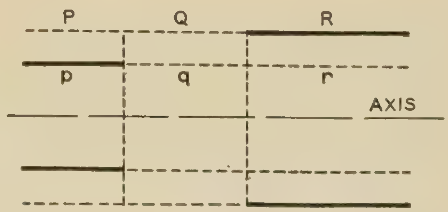

Fig. 2. Coaxial solenoids

[3] "The Force Between Unequal Reactance Coils Having Parallel Axes," by . B. Dwight and R. W. Purssell, *General Electric Review*, volume 33, July 30, page 401, formulas (1), (2), and (3).

formula uncertain and unsatisfactory (see pages 63 and 222 of Scientific Paper 169).

The following formula (17) is presented as an alternative to (43)A. Its coefficients λ_n and ξ_n are always less than unity and so it is possible to tell by inspection from the value of δ/ρ how rapid is the convergence of the series (17), which is a power series in δ/ρ. The change lowers the powers of some of the letters making up the terms. By putting

$$\delta^2 = a^2 + m_1^2 \tag{15}$$

and

$$\rho^2 = A^2 + m_2^2 \tag{16}$$

we can replace

m_1^2 by $\delta^2 - a^2$ and m_2^2 by $\rho^2 - A^2$ in (43)A

giving for the concentric coils,

$$M = \frac{2\pi^2a^2N_1N_2}{\rho}\left[1 - \frac{A^2\delta^2}{2\rho^4}\left\{\lambda_2 + \frac{\delta^2}{\rho^2}\lambda_4\xi_2 + \frac{\delta^4}{\rho^4}\lambda_6\xi_4 + \frac{\delta^6}{\rho^6}\lambda_8\xi_6 + \ldots\right\}\right] \tag{17}$$

where N_1 and N_2 are the turns per coil of the 2 coils, respectively, and where

$$\lambda_2 = 1 - \frac{7}{4}\frac{a^2}{\delta^2} \qquad \xi_2 = 1 - \frac{7}{4}\frac{A^2}{\rho^2}$$

$$\lambda_4 = 1 - \frac{9}{2}\frac{a^2}{\delta^2} + \frac{33}{8}\frac{a^4}{\delta^4} \qquad \xi_4 = 1 - \frac{9}{2}\frac{A^2}{\rho^2} + \frac{33}{8}\frac{A^4}{\rho^4}$$

$$\lambda_6 = 1 - \frac{33}{4}\frac{a^2}{\delta^2} + \frac{143}{8}\frac{a^4}{\delta^4} - \frac{715}{64}\frac{a^6}{\delta^6}$$

$$\lambda_8 = 1 - 13\frac{a^2}{\delta^2} + \frac{195}{4}\frac{a^4}{\delta^4} - \frac{1105}{16}\frac{a^6}{\delta^6} + \frac{4199}{128}\frac{a^8}{\delta^8}$$

$$\lambda_{10} = 1 - \frac{75}{4}\frac{a^2}{\delta^2} + \frac{425}{4}\frac{a^4}{\delta^4} - \frac{8075}{32}\frac{a^6}{\delta^6} + \frac{33915}{128}\frac{a^8}{\delta^8} - \frac{52003}{512}\frac{a^{10}}{\delta^{10}}$$

The coefficients ξ_6, ξ_8, etc., are functions of A^2/ρ^2 and can be written down by inspection from the similar expressions for λ_6, λ_8, etc.

While formulas (17) and (43)A are given for the case of the mutual inductance of a short solenoid and a longer one outside, these formulas can be used for the case when the shorter solenoid is outside, by first applying the principle of interchange of lengths.

Gray's[4] formula (40)A expresses the mutual inductance of 2 coaxial solenoids, not concentric, as the difference of 2 series of terms. It may be derived from the general formula (1) and (7) by expressing the 4 distances r in terms of the distances measured from the center of the coil of smaller radius to the ends of the winding of the other coil. In spite of its smaller number of terms, however, the convergence of Gray's formula is not so good as that of (7), except for coils far apart.

Since Gray's formula contains the same coefficient as (43)A, it is subject to the same disadvantage that, for certain proportions of coils, the coefficients become large and it cannot be told by inspection how satisfactory is the convergence of the series. By making the same type of substitution as was used for obtaining (17), the following alternative form of Gray's formula for 2 coils as in figure 1, is obtained:

$$M = \frac{4\pi^2a^2n_1n_2m_1q_2}{d_2}\left[1 - \frac{A^2\delta^2}{2d_2^4}\left\{\lambda_2 + \left(\frac{\delta}{d_2}\right)^2\lambda_4\xi_2'' + \left(\frac{\delta}{d_2}\right)^4\lambda_6\xi_4'' + \ldots\right\}\right] - \frac{4\pi^2a^2n_1n_2m_1q_1}{d_1}\left[1 - \frac{A^2\delta^2}{2d_1^4}\left\{\lambda_2 + \left(\frac{\delta}{d_1}\right)^2\lambda_4\xi_2' + \left(\frac{\delta}{\delta_1}\right)^4\lambda_6\xi_4' + \ldots\right\}\right] \tag{18}$$

where

$$q_1 = s - m_2$$
$$q_2 = s + m_2$$
$$d_1^2 = A^2 + q_1^2$$
$$d_2^2 = A^2 + q_2^2$$
$$\delta^2 = a^2 + m_1^2$$

where λ_2, λ_4, etc., are the same as for (17), where ξ_n' is the same function of A/d_1 that λ_n is of a/δ and where ξ_n'' is the same function of A/d_2 that λ_n is of a/δ. The quantities n_1 and n_2 are the numbers of turns per centimeter of the 2 coils, respectively.

Since the coefficients in (18) are less than unity, the rapidity of convergence of the series is evident at once from the values of δ/d_1 and δ/d_2. The formula also has been simplified to some extent.

If the 2 coils of figure 1 are concentric, $s = 0$, $d_1 = d_2$ and (18) becomes the same as (17).

The convergence of (18) may be improved by employing the principle of interchange of lengths if, by so doing, a smaller value of δ results.

The convergence of Gray's formula and the alternative form (18), like that of (7) and (9), improves as the distance between the 2 solenoids is increased, but for loosely coupled coils this advantage is offset by the difficulty that the mutual inductance is obtained as the small difference of much larger terms. Thus each series has to be calculated to a much higher accuracy than that required in the value of the mutual inductance.

This difficulty may be avoided by the use of a new formula derived from (18).

Writing

$$d_1 = q_1\sqrt{1 + \frac{A^2}{q_1^2}} \quad \text{and} \quad d_2 = q_2\sqrt{1 + \frac{A^2}{q_2^2}}$$

and expanding powers of d_1 and d_2 in (18) by the binomial theorem, there results the expression

$$M = \frac{2\pi^2a^2A^2N_1N_2s}{q_1^2q_2^2}\left[1 + \frac{2\delta^2}{q_1^2}\left(\lambda_2 - \frac{3}{4}\frac{A^2}{\delta^2}\right)\left(1 + \frac{m_2^2}{s^2}\right)\frac{s^2}{q_2^2} + \frac{3\delta^4}{q_1^4}\left(\lambda_4 - \frac{5}{2}\frac{A^2}{\delta^2}\lambda_2 + \frac{5}{8}\frac{A^4}{\delta^4}\right)\left(1 + \frac{10}{3}\frac{m_2^2}{s^2} + \frac{m_2^4}{s^4}\right)\frac{s^4}{q_2^4} + \frac{4\delta^6}{q_1^6}\left(\lambda_6 - \frac{21}{4}\lambda_4\frac{A^2}{\delta^2} + \frac{35}{8}\frac{A^4}{\delta^4}\lambda_2 - \frac{35}{64}\frac{A^6}{\delta^6}\right)\times \left(1 + 7\frac{m_2^2}{s^2} + 7\frac{m_2^4}{s^4} + \frac{m_2^6}{s^6}\right)\frac{s^6}{q_2^6} + \ldots\right] \tag{19}$$

[4] "Absolute Measurements in Electricity and Magnetism," by Andrew Gray, edition of 1893, volume 2, part 1, page 274, equation 53, and Scientific Paper 169 of the Bureau of Standards, by E. B. Rosa and F. W. Grover, page 59, equation 40 and 40a.

n which N_1 and N_2 are the total numbers of turns on the coils.

This formula is simpler and more accurate the looser the coupling of the coils, that is, in just those cases where formulas (1) and (7) require the greatest care. The coefficients of δ^n/q_1^n are less than unity.

Here also the principle of interchange of lengths should be employed so that δ may have the smaller of the 2 lengths which are possible.

When the 2 coils are not concentric, a mechanical force is exerted by one on the other in the direction of the axis. By a well-known proposition, this force is equal to

$$i_1 i_2 \frac{\partial M}{\partial s} \text{ dynes}$$

where i_1 and i_2 are in abamperes. This can be written

$$i_1 i_2 n_1 n_2 [Q_{(x_1)} - Q_{(x_2)} - Q_{(x_3)} + Q_{(x_4)}] \text{ dynes} \tag{20}$$

where x_1 to x_4 are given by (2) to (5) and where

$$Q_{(x)} = \frac{\partial F_{(x)}}{\partial x}$$

since

$$\partial s = \partial x$$

For small values of x, the derivative of (6) may be taken from the first step of the integration by which (6) was obtained. This gives

$$\begin{aligned}Q_{(x)} = \pi x \sqrt{Dd} \Bigg[&\left\{ \operatorname{log n} \frac{16Dd}{x^2 + c^2} \right\} \left\{ 1 + \frac{3}{4} \frac{c^2}{Dd} - \frac{15}{64} \frac{c^4}{D^2d^2} + \right.\\ &\frac{35}{256} \frac{c^6}{D^3d^3} + \frac{x^2}{4Dd} \left(1 - \frac{5}{8} \frac{c^2}{Dd} + \frac{35}{64} \frac{c^4}{D^2d^2} \right) - \frac{3}{64} \frac{x^4}{D^2d^2} \times \\ &\left. \left(1 - \frac{7}{4} \frac{c^2}{Dd} \right) + \frac{5}{256} \frac{x^6}{D^3d^3} \cdots \right\} - \left\{ \frac{2c}{x} \tan^{-1} \frac{x}{c} \right\} \times \\ &\left\{ 1 + \frac{c^2}{2Dd} - \frac{c^4}{8D^2d^2} + \frac{c^6}{16D^3d^3} \right\} + \left(-2 + \frac{c^2}{2Dd} + \right.\\ &\left. \frac{15}{64} \frac{c^4}{D^2d^2} - \frac{151}{768} \frac{c^6}{D^3d^3} \right) + \frac{x^2}{Dd} \left(\frac{c^2}{4Dd} - \frac{209}{768} \frac{c^4}{D^2d^2} \right) + \\ &\frac{x^4}{D^2d^2} \left(\frac{5}{64} - \frac{43}{256} \frac{c^2}{Dd} \right) - \frac{31}{768} \frac{x^6}{D^3d^3} \cdots \Bigg]\end{aligned} \tag{21}$$

For larger values of x the following expression for $Q_{(x)}$ may be obtained by differentiating (7) with respect to x:

$$\begin{aligned}Q_{(x)} = \frac{2\pi^2 a^2 x}{r} \Bigg[&1 + \frac{3}{8} \frac{a^2A^2}{r^4} - \frac{5}{16} \frac{a^4A^2}{r^6} + \frac{35}{64} \frac{a^4A^4}{r^8} + \\ &\frac{35}{128} \frac{a^6A^2}{r^8} - \frac{315}{256} \frac{a^6A^4}{r^{10}} - \frac{63}{256} \frac{a^8A^2}{r^{10}} + \frac{1155}{1024} \frac{a^6A^6}{r^{12}} + \\ &\frac{2079}{1024} \frac{a^8A^4}{r^{12}} + \frac{231}{1024} \frac{a^{10}A^2}{r^{12}} - \frac{9009}{2048} \frac{a^8A^6}{r^{14}} - \frac{3003}{1024} \frac{a^{10}A^4}{r^{14}} - \\ &\frac{429}{2048} \frac{a^{12}A^2}{r^{14}} + \cdots \Bigg]\end{aligned} \tag{22}$$

where

$$r^2 = x^2 + A^2$$

It is easy to show that the mutual inductance $m(x)$ of a solenoid of radius A, winding density n_1, length x, and a coaxial circle of radius a in its end plane is connected with the function $Q(x)$ by the relation $m(x) = n_1 Q(x)$. Thus equation (22), multiplied by n_1, gives an expression for the mutual inductance of a solenoid and coaxial circle which is equivalent to (56)A and may in fact be derived from the latter by putting $x^2 = r^2 - A^2$ and collecting like terms. This change is similar to that used in obtaining (17) and (18), and the formula thus derived has the advantage, already noted in these cases also, of avoiding the possibility of large values of the coil length in the numerators of the terms. In (22) A^2/r^2 is always less than unity.

Similarly, by multiplying equation (21) by n_1, a second formula for the mutual inductance of solenoid and coaxial circle is found, which is suitable for short coils, and those cases where the radii are nearly equal. This formula is believed to be new. The fact that (21) is unchanged, when d and D are interchanged, furnished a proof of the principle of interchange of lengths in the special cases of solenoid and circle also.

The equations for $m(x)$, derived from (21) and (22), are to be used twice, when the plane of the circle does not pass through the end of the solenoid.

It is desired to make acknowledgment of preliminary investigations on this subject done in connection with thesis work by T. S. Chen at Massachusetts Institute of Technology.

Example I. A mutual inductance problem where both (6) and (7) can be used to check each other.

$A = 25$, $m_2 = 3$, $a = 20$, $m_1 = 2$, $s = 30$ (centimeter units).

$x_1 = 35$, $x_2 = 29$, $x_3 = 31$, $x_4 = 25$

$$\begin{aligned}F_{(x_1)} \text{ by (6)} &= 10{,}000\pi\sqrt{12.80}\,[0.0614 + 2.6824 - 0.6290 - 0.7549 + 0.0299 + 0.0058 - 0.0016] = 156700\\ F_{(x_1)} \text{ by (7)} &= 20{,}000\,\pi^2\,[1.7205 - 0.0157 + 0.0017 - 0.0007 - 0.0002 + 0.0003 - 0.0001 - 0.0001) + (-1.0000 + 0.0800 + 0.0064 + 0.0013 + 0.0004)]\\ &= 20{,}000\,\pi^2\,(1.7057 - 0.9119)\\ &= 156700\end{aligned}$$

In a case such as this, where both (6) and (7) are applicable, not many significant figures can be obtained. However, if (6) is used for a much smaller value of x, or (7) for a larger value, the last terms may be smaller than 10^{-7} and so 7 or more significant figures can be obtained.

Example II. $Q(x_1)$ for the coils of example I, by (21),

$$\begin{aligned}&= 35\,\pi\sqrt{2000}\,[3.721 - 0.411 - 1.994 + 0.002 + 0.029 - 0.009]\\ &= 6580\end{aligned}$$

$$\text{By (22)},\ Q_{(x_1)} = \frac{2\,\pi^2 \times 400 \times 35}{\sqrt{1850}}\,[1 + 0.0274 - 0.0049 + 0.0029 + 0.0009 - 0.0014 - 0.0002 + 0.0004 + 0.0005 - 0.0004 - 0.0002] = 6580$$

Example III. Two concentric, coaxial coils.

Inner solenoid, $a = 2$, $2m_1 = 2$

Outer solenoid, $A = 10$, $2m_2 = 5$

(Example 39, page 84, Scientific Paper 169)

$$\frac{M}{n_1 n_2} = 160\,\pi^2\,(1.055268 - 1.006331) = 77.279 \text{ by (7).}$$

Equation (43) of Scientific Paper 169 gives 77.27980. It is a better series for this case, in which the coils are too short for more than 5 significant figures to be given by

(7), and in which $c^2/Dd = 0.8$ is too large for (6) to be used. However, equation (7) is applicable to coils which are not concentric, while (43) is not.

Example IV. Two concentric, coaxial solenoids.

Inner solenoid, $a = 10$, $2m_1 = 20$
Outer solenoid, $A = 15$, $2m_2 = 200$
(Example 43, page 91, Scientific Paper 169)

$$\text{By (7)},\ F(110) = 3000\,\pi^2\,(7.401200 - 0.000137 + 0.000001) = 3000\,\pi^2 \times 7.401064$$

$$F(90) = 3000\,\pi^2\,(6.082762 - 0.000247 + 0.000001) = 3000\,\pi^2 \times 6.082516$$

$$\frac{M}{n_1 n_2} = 6000\,\pi^2\,(7.401064 - 6.082516)$$

$$\frac{M}{4\pi n_1 n_2} = 6213.51$$

This agrees with the values given on page 91 of Scientific Paper 169. On page 92, a solution which occupies more than a page, is given by means of (45), page 65 of that paper, which is a formula for 2 coaxial solenoids which may or may not be concentric. As stated on page 91, if a series formula can give the accuracy required, it is usually preferable to (45). It is evident that, by using more terms of (7) of this paper, more than 6 significant figures could be obtained in this case.

Example V. As an example of the use of formula (19) there may be taken the case where

$a = 2$, $A = 3$, $2m_1 = 10$, $2m_2 = 6$, $s = 18$

Assuming further that $n_1 = n_2 = 10$ it follows that the coils have 100 turns and 60 turns, respectively.

$q_1 = 15$, $q_2 = 21$, $\delta^2 = 29$

Then (19) gives

$$M = \frac{7.776\,\pi^2\,10^6}{(315)^2}\,[1 + 0.102358 - 0.002076 - 0.001099\ldots] = 850.17$$

A more convergent series is obtained if the lengths are interchanged, giving

$2m_1 = 6$, $2m_2 = 10$, $s = 18$, $q_1 = 13$, $q_2 = 23$, and $\delta^2 = 13$.

The mutual inductance is then

$$M = \frac{7.776\,\pi^2\,10^6}{(299)^2}\,[1 - 0.005855 - 0.004150 + 0.000392 + \ldots] = 850.19$$

If the solution be carried through by (18), $M = 8{,}000\,\pi^2\,[0.989447 - 0.978679] = 850.21$ with $2m_1 = 10$ and $2m_2 = 6$, and if the lengths be interchanged,

$$n = 4800\,\pi^2\,[0.991508 - 0.973561] = 850.22$$

Appendix

Formulas From the Bureau of Standards Collection for the Calculation of Inductance (Scientific Paper 169)

Formulas quoted in this paper are here collected for easy reference.

Mutual Inductance of Coaxial Circles

Placing
a = the smaller radius
A = the larger radius
$c = A - a$ = the difference of the radii
x = the distance between their planes
$r^2 = c^2 + x^2$ and $\alpha^2 = \dfrac{r^2}{Aa}$,

then Maxwell's series formula, extended by Rosa and Cohen, is

$$M = 4\pi a\left\{\log\frac{8a}{r}\cdot\left(1 + \frac{c}{2a} + \frac{c^2 + 3x^2}{16a^2} - \frac{c^3 + 3cx^2}{32a^3} + \frac{17c^4 + 42c^2x^2 - 15x^4}{1024a^4} - \ldots\right) - \left(2 + \frac{c}{2a} - \frac{3c^2 - x^2}{16a^2} + \frac{c^3 - 6cx^2}{48a^3} + \frac{19c^4 + 534c^2x^2 - 93x^4}{6144a^4} - \ldots\right)\right\} \quad \text{(14A)}$$

If the circles are in the same plane, $x = 0$, and this becomes

$$M = 4\pi a\left\{\log\frac{8a}{c}\cdot\left(1 + \frac{c}{2a} + \frac{c^2}{16a^2} - \frac{c^3}{32a^3} + \frac{17}{1024}\frac{c^4}{a^4} - \ldots\right) - \left(2 + \frac{c}{2a} - \frac{3}{16}\frac{c^2}{a^2} + \frac{c^3}{48a^3} + \frac{19}{6144}\frac{c^4}{a^4} - \ldots\right)\right\} \quad \text{(15A)}$$

A formula derived from series expansions of certain integrals by Havelock reads

$$M = 4\pi\sqrt{Aa}\left[\left(1 + \frac{3}{16}\alpha^2 - \frac{15}{1024}\alpha^4 + \frac{35}{(128)^2}\alpha^6 - \frac{1575}{2(128)^3}\alpha^8 + \ldots\right)\log\frac{8\sqrt{Aa}}{r} - \left(2 + \frac{\alpha^2}{16} - \frac{31}{2048}\alpha^4 + \frac{247}{6(128)^2}\alpha^6 - \frac{7795}{8(128)^3}\alpha^8 + \ldots\right)\right] \quad \text{(16A)}$$

This gives very accurate results for values of x almost as great as the smaller radius. For a given degree of convergence it requires only half as many terms to be calculated as does formula (14)A.

Mutual Inductance of A Solenoid and a Circle in Its End Plane

The mutual inductance of a solenoid of N turns, radius A, and axial length x, and a circle of radius a in its end plane may be found from Rosa's formula:

$$M = \frac{2\pi^2 a^2 N}{\rho}\left[1 + \frac{3}{8}\frac{a^2A^2}{\rho^4} + \frac{5}{64}\frac{a^4A^4}{\rho^8}X_2 + \frac{35}{512}\frac{a^6A^6}{\rho^{12}}X_4 + \frac{63}{1024}\frac{a^8A^8}{\rho^{16}}X_6 + \frac{231}{4096}\frac{a^{10}A^{10}}{\rho^{20}}X_8 + \frac{429}{8192}\frac{a^{12}A^{12}}{\rho^{24}}X_{10} + \ldots\right] \quad \text{(56A)}$$

in which $\rho^2 = x^2 + A^2$

and

$$X_2 = 3 - 4\frac{x^2}{A^2}$$

$$X_4 = \frac{5}{2} - 10\frac{x^2}{A^2} + 4\frac{x^4}{A^4}$$

$$X_6 = \frac{35}{16} - \frac{35}{2}\frac{x^2}{A^2} + 21\frac{x^4}{A^4} - 4\frac{x^6}{A^6}$$

$$X_8 = \frac{63}{32} - \frac{105}{4}\frac{x^2}{A^2} + 63\frac{x^4}{A^4} - 36\frac{x^6}{A^6} + 4\frac{x^8}{A^8}$$

$$X_{10} = \frac{231}{128} - \frac{1155}{32}\frac{x^2}{A^2} + \frac{1155}{8}\frac{x^4}{A^4} - 165\frac{x^6}{A^6} + 55\frac{x^8}{A^8} - 4\frac{x^{10}}{A^{10}}$$

and the general term for the coefficients X_{2n} is

$$X_{2n} = \sum_{p=0}^{n}\frac{(-1)^{n-p}(2n+1)2n(2n-1)\ldots[2n-(2p-2)]}{\left(\dfrac{p+1}{4}\right)[2.4.6\ldots(2p)]^2}\left(\frac{x}{A}\right)^{2n-2p}$$

when $p = 0$, the term being $4(-1)^n(x/A)^{2n}$.

Let the radius, axial length, and number of turns for the outer lenoid be A, $2m_2$, and N_2, and the corresponding quantities for e inner solenoid a, $2m_1$, and N_1. (This is a special case of figure with $s = 0$.)

Then, if the length of the outer solenoid be greater than that of e inner, the mutual inductance may be calculated by Searle and rey's formula:

$$= \frac{2\pi^2 a^2 N_1 N_2}{\rho}\Big[1 + \frac{1}{8}\frac{A^2a^2}{\rho^4}\cdot L_2 + \frac{1}{32}\frac{A^4a^4}{\rho^8}\cdot X_2L_4 + \frac{1}{32}\frac{A^6a^6}{\rho^{12}}\cdot X_4L_6 + \frac{1}{32}\frac{A^8a^8}{\rho^{16}}\cdot X_6L_8 + \ldots + \frac{1}{32}\left(\frac{Aa}{\rho^2}\right)^{2n}\cdot X_{2n-2}L_{2n} + \ldots\Big] \quad (43A)$$

which $\rho^2 = m_2^2 + A^2$, and the quantities X_{2n} are derived from e corresponding coefficients in $(56)A$, with m_2 in place of x, and e coefficients L_{2n} from the substitution of m_1 in place of x, and or A, in the same equations. Thus

$$= 3 - 4\frac{m_1^2}{a^2} \qquad X_2 = 3 - \frac{4m_2^2}{A^2}$$

$$= \frac{5}{2} - 10\frac{m_1^2}{a^2} + 4\frac{m_1^4}{a^4} \qquad X_4 = \frac{5}{2} - 10\frac{m_2^2}{A^2} + \frac{4m_2^4}{A^4}$$

This formula is very convergent, except for coils of nearly equal dii and of lengths which are short, compared with their radii.

For long coils, the coefficients X_{2n} and L_{2n} oscillate between ge positive and negative values, rendering it difficult to be sure the degree of convergence attained.

Ròiti's Formula. With the same nomenclature but with

$$= (m_2 - m_1)^2 + A^2 \qquad \text{and} \qquad \rho_2^2 = (m_2 + m_1)^2 + A^2$$

s formula may be written

$$= 4\pi^2a^2n_1n_2\Big[(\rho_2 - \rho_1) + \frac{a^2A^2}{8}\left(\frac{1}{\rho_1^3} - \frac{1}{\rho_2^3}\right) - \frac{a^4A^2}{16}\left(\frac{1}{\rho_1^5} - \frac{1}{\rho_2^5}\right) + \frac{5}{64}a^4A^4\left(1 + \frac{1}{2}\frac{a^2}{A^2}\right)\left(\frac{1}{\rho_1^7} - \frac{1}{\rho_2^7}\right) - \frac{35}{256}a^6A^4\left(1 + \frac{1}{5}\frac{a^2}{A^2}\right)\left(\frac{1}{\rho_1^9} - \frac{1}{\rho_2^9}\right) + \frac{105}{1024}a^6A^6 \times \left(1 + \frac{9}{5}\frac{a^2}{A^2} + \frac{1}{5}\frac{a^4}{A^4}\right)\left(\frac{1}{\rho_1^{11}} - \frac{1}{\rho_2^{11}}\right) - \frac{693}{2048}a^8A^6 \times \left(1 + \frac{2}{3}\frac{a^2}{A^2} + \frac{1}{21}\frac{a^4}{A^4}\right)\left(\frac{1}{\rho_1^{13}} - \frac{1}{\rho_2^{13}}\right) + \frac{3003}{16384}a^8A^8 \times \left(1 + 4\frac{a^2}{A^2} + \frac{10}{7}\frac{a^4}{A^4} + \frac{1}{14}\frac{a^6}{A^6}\right)\left(\frac{1}{\rho_1^{15}} - \frac{1}{\rho_2^{15}}\right) - \ldots\Big] \quad (39A)$$

xwell's Formula for Concentric Solenoids of Equal Lengths. the common length be $2m$, and the winding densities, in turns centimeter, n_1 and n_2. Then, with $\rho^2 = (2m)^2 + A^2$

$$= 4\pi^2a^2n_1n_2[2m - 2A\alpha]$$

which

$$= \frac{A - \rho + 2m}{2A} - \frac{a^2}{16A^2}\left(1 - \frac{A^3}{\rho^3}\right) - \frac{a^4}{64A^4}\left(\frac{1}{2} + 2\frac{A^5}{\rho^5} - \frac{5}{2}\frac{A^7}{\rho^7}\right) - \frac{35}{2048}\frac{a^6}{A^6}\left(\frac{1}{7} - \frac{8}{7}\frac{A^7}{\rho^7} + 4\frac{A^9}{\rho^9} - 3\frac{A^{11}}{\rho^{11}}\right) - \frac{63}{2(128)^2}\frac{a^8}{A^8}\left(\frac{5}{9} + \frac{64}{9}\frac{A^9}{\rho^9} - 48\frac{A^{11}}{\rho^{11}} + 88\frac{A^{13}}{\rho^{13}} - \frac{143}{3}\frac{A^{15}}{\rho^{15}}\right) - \frac{231}{(512)^2}\frac{a^{10}}{A^{10}}\left(\frac{7}{11} - \frac{128}{11}\frac{A^{11}}{\rho^{11}} + 128\frac{A^{13}}{\rho^{13}} - 416\frac{A^{15}}{\rho^{15}} + 520\frac{A^{17}}{\rho^{17}} - 221\frac{A^{19}}{\rho^{19}}\right) - \frac{429}{2(1024)^2}\frac{a^{12}}{A^{12}}\left(\frac{21}{13} + \frac{512}{13}\frac{A^{13}}{\rho^{13}} - 640\frac{A^{15}}{\rho^{15}} + 3200\frac{A^{17}}{\rho^{17}} - 6800\frac{A^{19}}{\rho^{19}} + 6460\frac{A^{21}}{\rho^{21}} - 2261\frac{A^{23}}{\rho^{23}}\right)\ldots \quad (36A)$$

In this expression the general term of the series in powers of a^2/A^2 is, as was shown by Havelock,

$$-\frac{(2n-1)[1.3.5\ldots(2n-3)]^2}{2^{2n+1}n!\,(n+1)!}\left(\frac{a}{A}\right)^{2n}$$

Gray's Formula. Gray gave the following formula for the mutual inductance of coaxial solenoids, not concentric. With the notation of figure 1 and

$$q_1 = s - m_2,\ q_2 = s + m_2,\ d_1^2 = A^2 + q_1^2,\ d_2^2 = A^2 + q_2^2$$

Gray's formula becomes

$$M = \pi^2a^2A^2n_1n_2[K_1k_1 + K_3k_3 + K_5k_5 + \ldots] \quad (40A)$$

in which

$$K_1 = \frac{2}{A^2}\left(\frac{q_2}{d_2} - \frac{q_1}{d_1}\right)$$

$$K_3 = \frac{1}{2}\left(\frac{q_1}{d_1^5} - \frac{q_2}{d_2^5}\right)$$

$$K_5 = -\frac{A^2}{8}\left\{\frac{q_1}{d_1^9}\left(3 - 4\frac{q_1^2}{A^2}\right) - \frac{q_2}{d_2^9}\left(3 - 4\frac{q_2^2}{A^2}\right)\right\}$$

$$k_1 = 2m_1$$

$$k_3 = -a^2m_1\left(3 - 4\frac{m_1^2}{a^2}\right)$$

$$k_5 = a^4m_1\left(\frac{5}{2} - 10\frac{m_1^2}{a^2} + 4\frac{m_1^4}{a^4}\right)$$

MUTUAL INDUCTANCE BY MEANS OF SELF-INDUCTANCE FORMULAS

The mutual inductance of 2 coils having the same radii and the same number of turns per unit length may be calculated from a knowledge of several self-inductances.

If the 2 coils be designated as A and B, and a coil C, having the same radius and winding density, be imagined to exactly fill up the space between A and B, the inductance of coils A, B, and C in series will be

$$L_{ABC} = L_A + L_B + L_C + 2M_{AC} + 2M_{BC} + 2M_{AB}$$

Similarly, the self inductance of the coils A and C in series, and of B and C in series, are given by

$$L_{AC} = L_A + L_C + 2M_{AC}$$
$$L_{BC} = L_B + L_C + 2M_{BC}$$

Eliminating M_{AC} and M_{BC} in the equation above, we find

$$2M_{AB} = (L_{ABC} + L_C) - (L_{AC} + L_{BC}) \quad (51A)$$

If the radii of the 2 coils are equal but their winding densities n_1 and n_2 are unequal, the expression $(51)A$ may first be calculated, assuming unit winding density on each coil. The result so found, multiplied by n_1n_2, is the desired mutual inductance.

The self-inductances in $(51)A$ may, in general, be calculated by Nagaoka's formula and tables. For a coil of N turns, whose axial length $2m$ does not exceed its radius a, Coffin's extension of the Rayleigh and Niven formula is accurate and convenient.

$$L = 4\pi aN^2\left\{\log\frac{8a}{2m} - \frac{1}{2} + \frac{1}{8}\frac{m^2}{a^2}\left(\log\frac{8a}{2m} + \frac{1}{4}\right) - \frac{1}{64}\frac{m^4}{a^4}\left(\log\frac{8a}{2m} - \frac{2}{3}\right) + \frac{5}{1024}\frac{m^6}{a^6}\left(\log\frac{8a}{2m} - \frac{109}{120}\right) - \frac{35}{16384}\frac{m^8}{a^8}\left(\log\frac{8a}{2m} - \frac{431}{420}\right) + \ldots\right\} \quad (71A)$$

An Analysis of Copper-Oxide Rectifier Circuits

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Summary

THE analysis of circuits containing copper-oxide rectifiers is based upon the selection of a proper representation of the variable impedance of the rectifier element. In this analysis, the element is replaced by 2 constant resistances effective during the 2 directions of current flow through the rectifier. On the basis of this representation, an equivalent circuit is developed, which is a modification of the usual perfect rectifier circuit. The method is illustrated by analyzing circuits in which the loads consist of resistance and inductance and of resistance and capacitance. The computed results are then compared with observations made by an oscillograph.

Introduction

Copper-oxide rectifiers are finding greater use in connection with measurement of alternating voltages and currents. This is particularly true in connection with special electrical instruments designed to measure physical quantities such as motion, pressure, etc. It is often desirable to analyze the circuit in order to predict its operation, but the usual assumption, neglecting rectifier imperfections, is frequently not sufficiently accurate.

This paper presents an approximate representation of the copper-oxide rectifier, taking into account its asymmetrical conduction properties. Two constant resistances are introduced, to represent the direct and inverse properties of the real rectifier. Using this approximation, an equivalent circuit is established.

A general discussion of the methods used to analyze circuits, consisting of copper-oxide rectifiers is given, together with a consideration of the circuits for which the rectifier conducts during only part of the cycle. The analysis is made on the assumptions that the applied voltage is sinusoidal with a constant maximum value, and that the successive half-waves are identical.

Circuits of resistance, resistance and inductance, and capacitance in parallel with resistance, are analyzed to show the application of the method presented in this paper. The circuits are also analyzed for the usual idealization of perfect rectifiers. The theoretical wave forms computed by each of these 2 methods is compared with the results obtained by an oscillographic study of an example of each type of load mentioned. The measurements included in this paper were made on commercial rectifiers and are included only as illustrations of the method of circuit analysis.

The Rectifier Element

Grondahl[1,2] has given an excellent description of the copper-oxide rectifier and its construction, together with an explanation of some of its properties. The rectifier element consists of a disk of copper upon one side of which an oxide has been formed by heat treatment. Rectification takes place in the area of contact between the copper and its oxide, because the impedance to current flow from oxide to copper is low, while the impedance to current flow, in the opposite direction, is high.

The difference in impedance for the 2 directions of flow presents a problem which has no simple solution, but which is, nevertheless, of much importance. Without an analytical approach, it would be necessary to make an oscillographic study of wave form to determine the behavior of each new circuit. It is desirable to obtain a method of computing results to be anticipated for a given circuit, so that the oscillographic study can be eliminated. This is especially true in the design of instruments using rectifiers.

For circuit analysis, the rectifier must be replaced by some combination of standard impedances. Deutschmann and Schottky[3] presented 4 types of equivalent combinations, of which pure resistance is the simplest, yet representative for many applications. This resistance is a variable depending upon the voltage applied to the rectifier element. The type of variation is shown in figure 1, but actual values will differ depending upon the kind of rectifier and size of disk.

Since the resistance varies continually during the cyclic change of current and voltage, an exact analysis is quite difficult. As an approximation, Cremer[4] replaced the changing resistances by 2 constant values, D and S, where D represents an equivalent constant value for current flow from oxide to copper, and S an equivalent constant value for current flow in the opposite direction. These approximations are used in this paper to simplify the study of rectifier circuits. The term "constant rectifier" refers to one in which the approximation of 2 constant resistances is used. A "perfect rectifier" is one in which D is zero and S is infinite.

Full-Wave Rectifier Circuits

There are 2 standard circuits used to obtain full wave rectification, the transformer bridge and the Graetz bridge, shown in figure 2. The choice between them depends upon the relative cost of rectifier elements and transformer, and also on certain conditions peculiar to

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1. For all numbered references see list at end of paper.

special problem. Unless otherwise stated, this paper als with the Graetz bridge only.

The rectifiers in the bridge of figure 2b may be replaced the approximate equivalent resistances, D and S, for ect and inverse impedances, respectively, and an ernating voltage of constant maximum value applied. hen a has a positive potential, current flows from a to Rectifiers in legs ab and dc are conducting and are presented by the constant direct resistance, D. Recti- rs in legs bc and ad are opposing the flow of current d are represented by the constant inverse resistance, During the next half-cycle, when c is positive, current ws from c to a, opposite to the direction in the previous lf-cycle. Thus rectifiers in legs ab and dc now oppose flow of current and are represented by S, while those legs bc and ad are conducting and are represented D.

If the rectifiers may be assumed to have like character- ics, the entire behavior can be described by one half- cle. This assumption simplifies the discussion and is

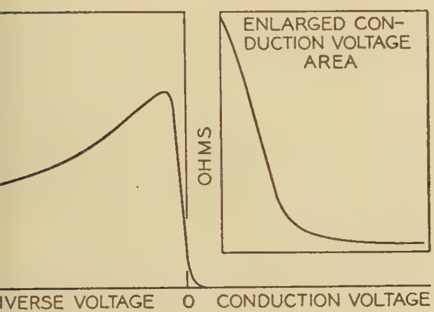


Fig. 1. Copper-oxide rectifier resistance variation

ed here. Thus the analysis is confined to the half- cle of voltage, where a is positive, the next half-cycle umed identical to it.

Analysis of the Graetz bridge circuit of circuits abc, lc, and junction b in figure 2b, yields the equations

$$+ Si_S = e$$
$$i_D + e_L = e$$
$$= i_D - i_S$$

mbining the first and third, gives

$$= \frac{e + Si_L}{D + S} \quad \text{and} \quad i_S = \frac{e - Di_L}{D + S}$$

bstitution of i_D in the second equation above, gives basic Graetz bridge equation

$$= e_L + Pi_L \tag{1}$$

ere

$$= \frac{2DS}{D + S} \quad \text{and} \quad \phi = \frac{S - D}{S + D}$$

An equivalent circuit, to represent the constant rec- er with load, can be set up from equation 1. The d current, i_L, for a constant rectifier, may be found by ling a resistance, P, in series with a perfect rectifier, ring the same load, and applying a voltage ϕe to the ulting circuit. This substitution is used here to solve the constant rectifier problem. A circuit of this kind is shown in figure 4c.

Applying similar analysis to the transformer bridge in figure 2a, the analogous equations become

$$i_D = \frac{2e + Si_L}{D + S}; \quad i_s = \frac{2e - Di_L}{D + S}; \quad \phi e = \frac{P}{2} i_L + e_L$$

where P and ϕ are the same as defined above. Thus the constant transformer bridge can be represented by a perfect rectifier bridge with a series resistance, $P/2$, and a voltage ϕe applied to the system.

Determination of Equivalent Resistances

Even if the curve of d-c values of figure 1 were known, the equivalent dynamic values, D and S, could not be easily established and so some method of direct meas- urement is desirable.

These constants may be determined by 2 sets of meas- urements on the Graetz bridge. Using the assembled rectifier bridge, measure the alternating current and volt- age with effective value meters, for these 2 conditions: (a) d-c load terminals open, and (b) d-c load terminals shorted. Call the impedance from the first measure- ment, the open-circuit impedance, Z_o, and the impedance from the second measurement, the short-circuit imped- ance, Z_S. Study of the parallel impedances of figure 3 shows that

$$Z_o = \frac{D + S}{2} \approx \frac{S}{2} \quad \text{and} \quad Z_S = \frac{2DS}{D + S} = P$$

Since S is much greater than D, the following definitions hold,

$$S \approx 2Z_O; \qquad D \approx P/2; \qquad \phi = \frac{S - D}{S + D} = 1 - \frac{P}{S}$$

$Z_S = P$ is concerned primarily with rectifier conduction, and so in use depends upon the current, while Z_O is con- cerned primarily with the inverse or leakage character- istic of the rectifier and in use depends upon the voltage.

For any given case, the values of P and S can be found from graphs similar to figure 3, the value of line current determining P, and the line voltage determining S.

Some precautions must be taken in the measurement of Z_O to obtain consistent and reliable results. A fairly good set of measurements can be obtained by taking the readings with decreasing voltages, controlling the voltage by a tapped transformer rather than with a potentiometer.

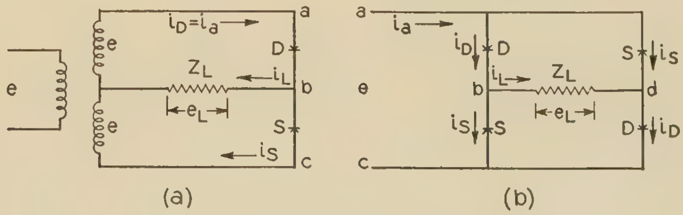


Fig. 2. Full-wave rectifier circuits

a—Transformer bridge b—Graetz bridge

Analysis of Rectifier Circuits With D-C Loads

Now that the equivalent circuit for the constant rectifier has been established, and an experimental means for finding P and ϕ has been presented, a few typical circuits will be analyzed to show the application of equation 1. Comparison of the wave forms obtained by this method will be made with the wave forms obtained by oscillographic study of the circuit. The analysis of these loads will also be made assuming a perfect rectifier, for the purpose of comparing results with those obtained by the constant rectifier method.

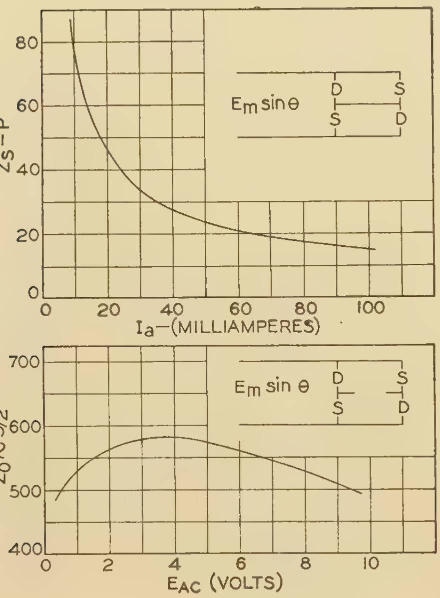


Fig. 3. Equivalent resistance determination

Several studies of perfect rectifier circuits have been published. The reader is referred to the series methods presented by Wheatcroft[5] and by Stout.[6] A filter circuit study was made by Lee[7] and the equations for a thyratron rectifier were given by Cockrell.[8]

Distinction must be made, in rectifier work, between 2 kinds of loads;

a. Loads for which rectifier conducts during the entire half-cycle. Most of the loads under this group are resistance and inductance in series or pure resistance, but some arrangements of capacitance in parallel with series inductance and resistances fall into this group. A discussion of a load of resistance and inductance in series is presented to illustrate this type.

b. A second group of loads are those having parallel capacitance of such magnitude that the load current tends to become negative during the half-wave, with the result that the rectifier stops conducting and a cut-off period must be studied in addition to the usual conduction period. A discussion of this type of load follows and the case of resistance and capacitance in parallel illustrates this kind of load.

The circuit analyses in this paper are made with the following assumptions:

1. The impressed alternating voltage is sinusoidal with a constant maximum value, $e = E_m \sin \omega t = E_m \sin \theta$.

2. It is assumed that the system has been in operation for sufficient time so that a steady state has been reached.

3. The successive half-waves are identical. All wave-forms and developments are based on the half-cycle, $\theta = 0$, to $\theta = \pi$.

4. Since the successive half-waves are identical, the currents must have the same value at $\theta = 0$ as at $\theta = \pi$.

Load of Resistance and Inductance in Series

As mentioned above, a load of resistance and inductance in series is an example of the group in which the rectifier conducts during the entire half-cycle. See figure 4 for the circuits for this type of load.

Perfect Rectifier

Refer to figure 4*b* for the equivalent circuit for this case. The rectifier impedance is zero and so the current solution is obtained by applying the voltage directly to the load. The equation for this case is

$$Ri_L + L\frac{di_L}{dt} = E_m \sin\theta$$

which has the solution

$$i_L = K_1\epsilon^{-a\theta} + K_2 \sin\theta + K_3 \cos\theta$$

where $a = R\omega/L$. K_1 is obtained from the condition that i_L is the same for $\theta = 0$ and $\theta = \pi$. K_2 and K_3 are known from the steady state of the inductive circuit for alternating voltage, so that

$$K_1 = \frac{\omega L E_m}{R^2 + (\omega L)^2}\,\frac{2}{1-\epsilon^{-a\pi}};\quad a = \frac{R}{\omega L}$$

$$K_2 = \frac{RE_m}{R^2 + (\omega L)^2};\quad K_3 = \frac{-\omega L E_m}{R^2 + (\omega L)^2}$$

Constant Rectifier

Refer to figure 4*c*. Equation 1 and its discussion show that the constant rectifier can be represented by a perfect rectifier with a series resistance, P, and a modified voltage, ϕe. Thus the same equations that were developed for the perfect rectifier are valid, except that the

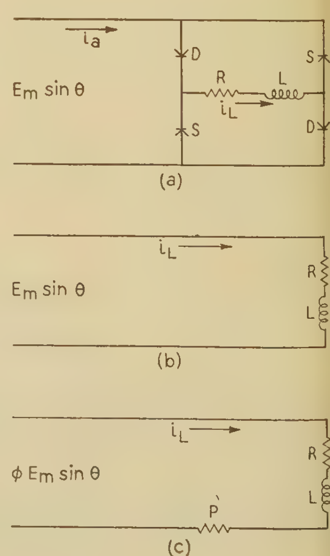


Fig. 4. Graetz bridge circuits for resistance and inductance in series

a—Conventional circuit, first half-wave

b—Equivalent circuit for perfect rectifier

c—Equivalent circuit for constant rectifier

istance term, R, is replaced by the term $(R + P)$. ius we can write the coefficients directly

$$= \frac{\omega L \phi E_m}{(R+P)^2 + (\omega L)^2} \frac{2}{1 - \epsilon^{-a\pi}}; \quad a = \frac{R+P}{\omega L}$$

$$= -\frac{\omega L \phi E_m}{(R+P)^2 + (\omega L)^2}; \quad K_2 = \frac{(R+P)^2 \phi E_m}{(R+P)^2 + (\omega L)^2}$$

For resistance only the equations become

$$= \frac{E_m}{R} \sin \theta, \text{ for perfect rectifier}$$

$$= \frac{\phi E_m}{R+P} \sin \theta, \text{ for constant rectifier}$$

Figures 5 and 6 show the comparison of wave-forms mputed from the above formulas, with an observed ive-form obtained from loads of resistance and from sistance and inductance in series. Figure 5a shows at the computed forms differ from the observed, but e constant rectifier method gives a much closer approximation than the perfect rectifier, the reason being that the load is of the same order of magnitude as the direct resistance of the rectifier and so the rectifier resistance cannot be neglected. A similar discrepancy will be found if the load is of the same order of magnitude as the inverse resistance of the rectifier, in which case the assumption of infinite resistance is in error.

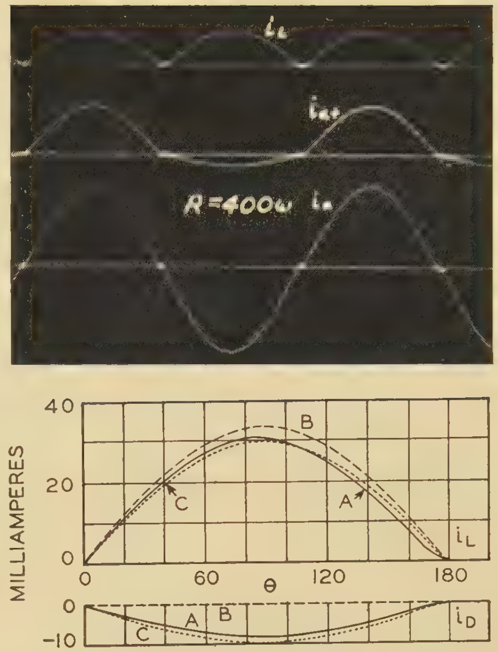


Fig. 5b. Comparison with typical case of resistance load

A—Oscillogram
B—Perfect rectifier
C—Constant rectifier
R = 400 ohms, E_m = 13.7 volts, ω = 377

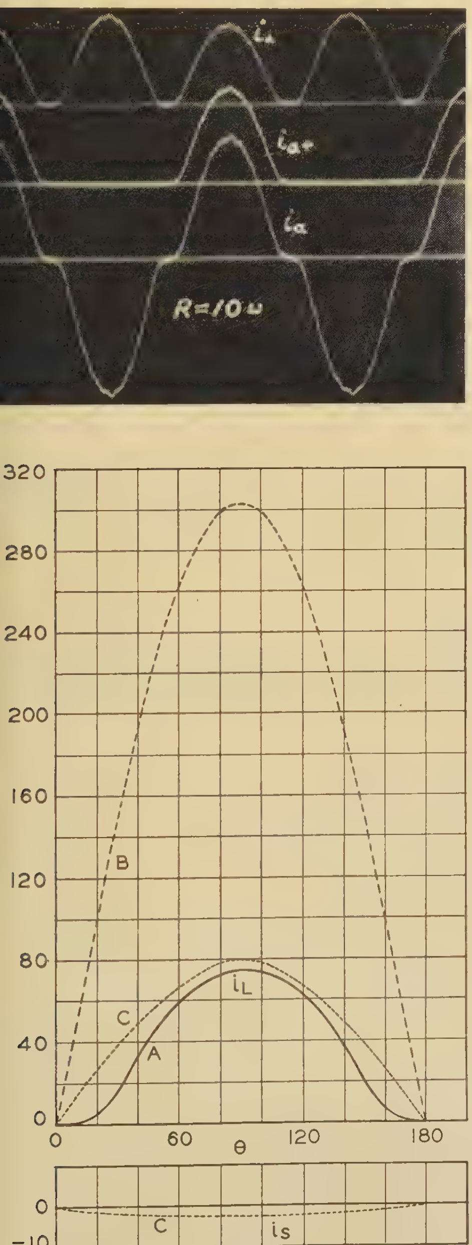


Fig. 5a. Comparison with typical case of resistance load

R = 10 ohms, E_m = 3.1 volts, ω = 377
A—Oscillogram
B—Perfect rectifier
C—Constant rectifier

Circuits That Have Cut-Off

For the group of loads having a cut-off period, the load current tends to become negative at some point in the cycle. The rectifier does not allow this and so a different type of behavior takes place during the rest of the cycle. These loads have 2 or more paths in parallel, one or more of which contain capacitance. A typical circuit of this type is shown in figure 8a.

Reference to figure 7 will aid the following discussion. Begin consideration sometime during the conduction period, when the voltage e is the voltage applied to the load, and the circuit follows its normal a-c behavior until θ_2 is reached. At that point the current through leg D reaches zero due to the fact that the condenser discharge becomes sufficient to supply the load.

After θ_2, the current through leg D reverses and legs ab and dc change their characteristic from D to S. Legs bc and ad retain their S characteristic since they experience no change in current direction. The circuit is now that for cut-off as shown in figure 8d. This cut-off period begins at θ_2, the cut-off angle. Its significance can be most easily seen in the case of a perfect rectifier where S is infinite. At θ_2, the condenser has a charge corresponding to that voltage ($q = CE_m \sin \theta_2$) which must discharge through the resistance path, since the impedance in the outer circuit is infinite, or open circuited. This discharge continues until the voltage across it dies down to the voltage of the next oncoming sine wave, defined

as the cut-in angle at $\theta = \theta_1 + \pi$. At this point the condenser ceases to discharge and again charges according to sine voltage behavior. Thus the conduction period, or normal a-c behavior, continues from θ_1 to θ_2, and the cut-off period, or discharge of condenser, is from θ_2 to $\theta_1 + \pi$.

The discharge path in the constant rectifier case is the resistance branch in parallel with an S combination, shown in figure 8*f*. At θ_1 the legs *ab* and *dc* change their characteristic behavior from S to D and at θ_2 change back from D to S. Since this change is caused by a reversal of the current through these legs, the current must be equal to zero at the instant of change. But this current is i_D. Therefore θ_1 and θ_2 are defined as the values of θ when i_D equals zero. Since i_D equals zero, it can be seen that $e = e' = e_L$ at $\theta = \theta_1$ and $\theta = \theta_2$. This is a basic fact in solution for the current equations in these circuits.

A uniform procedure in problems of this type is given below and is further illustrated in the circuits following:

1. Set up the differential equation of the circuits for conduction and cut-off periods to obtain the general form of the currents, as well as the exponents of the transient terms.

2. Determine the steady state coefficients using the bridge equation 1 and other usual methods used in circuit analysis, such as parallel relations between the two load branches.

3. Determine the cut-off angle, using the definition that $i_D = 0$. It is necessary to assume that the transient term for the conduction section is zero at cut-off to facilitate solution. This assumption is quite reasonable since $\epsilon^{-a\theta}$ is usually a large damping factor which reduces the transient term to a small quantity by the time θ_2 is reached.

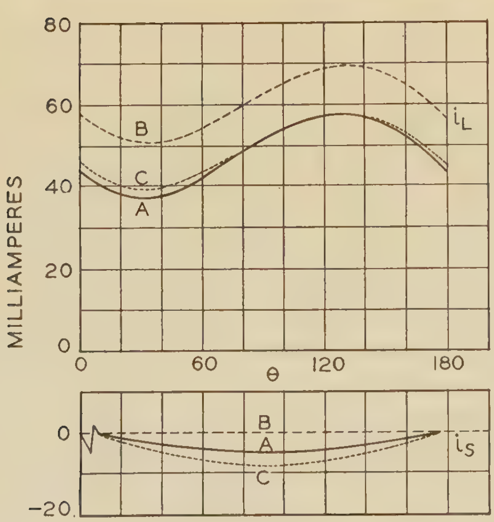


Fig. 6. Comparison with typical case of resistance and inductance in series

A—Oscillogram

B—Perfect rectifier

C—Constant rectifier

R = 122 ohms,
L = 0.65 henry,
E_m = 11.6 volts,
ω = 377

4. Determine the coefficients for the cut-off period using conditions of continuity, voltage equality, or others, at θ_2 and circuit relations during the cut-off period.

5. From conditions existing at $\theta_1 + \pi$ determine the value of the cut-in and the values of the transient term constants. It will be necessary to solve some of these equations by trial since they involve trigonometric and exponential terms.

6. Now knowing the transient term, check back and revise the cut-off angle, if necessary. (The new cut-off solution may be a trial solution.) Then repeat the steps 4 and 5, using the transient term as obtained. Continue until the desired accuracy is reached. Usually the revision produces but minor changes in the values. For simple circuits a graph or table can be set up giving θ_2 and θ_1 for given load conditions.

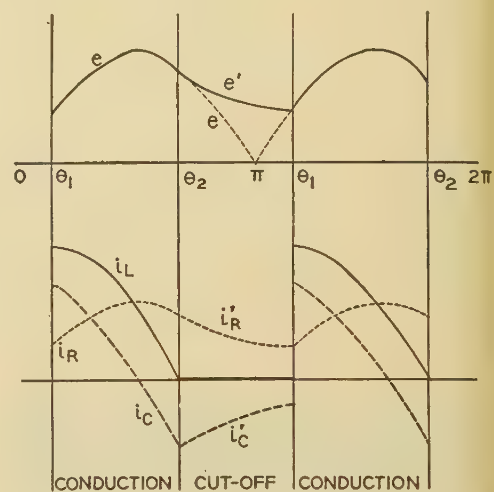


Fig. 7. Wave forms in a cut-off-circuit

Load of Resistance and Capacitance in Parallel

The load of resistance and capacitance in parallel is the simplest kind of load that falls into the cut-off group. The method of solving this circuit is outlined and the main equations given.

Perfect Rectifier

The equivalent circuits for this case are shown in figures 8*b* and 8*e*. The circuit equations for the 2 periods are:

During the conduction period:

$$i_R = \frac{E_m}{R}\sin\theta \quad \text{and} \quad i_C = \omega C E_m \cos\theta$$

During the cut-off period,

$$q' = h\epsilon^{-b\theta} \quad \text{where} \quad b = \frac{1}{\omega CR}$$

$$i_R' = -i_C' = \omega bh\epsilon^{-b\theta}; \qquad i_L' = i_D = i_S = 0$$

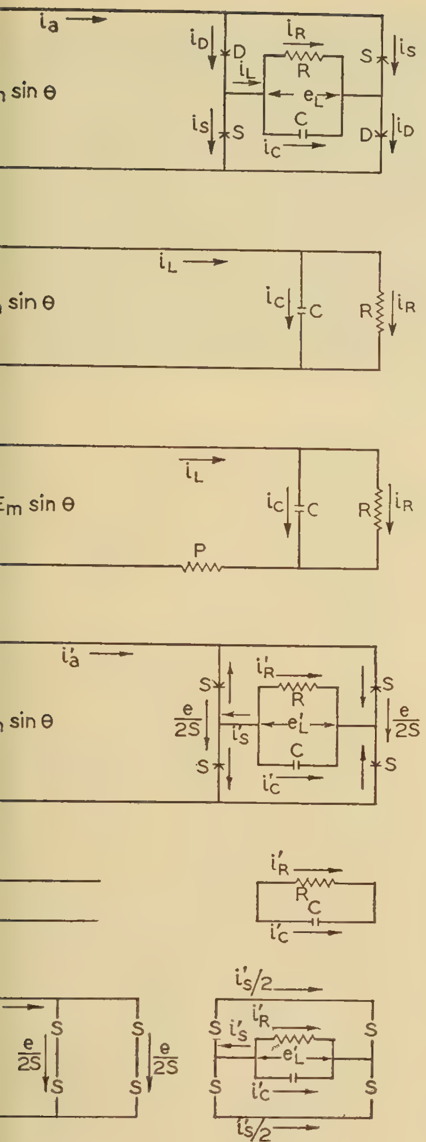
When θ equals the cut-off angle, θ_2, $i_D = 0$ and $e = e'$

$$\tan\theta_2 = \omega RC \quad \text{and} \quad h\epsilon^{-b\theta_2} = \omega C E_m \sin\theta_2$$

At the cut-in angle for the next half-cycle, $\theta = \theta_1 + \pi$,

$$e = e', \quad \text{also} \quad \sin\theta_1 = (\sin\theta_2)\epsilon^{-b(\theta_1+\pi-\theta_2)}$$

Knowing the coefficient, h, the cut-off and cut-in angles,



a—Conduction period currents

b—Equivalent circuit for perfect rectifier, during conduction

c—Equivalent circuit for constant rectifier, during conduction

d—Cut-off period currents

e—Equivalent circuits for perfect rectifier, during cut-off

f—Equivalent circuit for constant rectifier, during cut-off

and θ_1, the entire circuit behavior is determined for e perfect rectifier.

ONSTANT RECTIFIER

Figure 8*c* again shows the equivalent circuits for this se. The bridge equation 1 for this kind of circuit comes:

$$= \frac{q}{C} = Ri_R = \phi e - Pi_L$$

ring the conduction period. This equation has the lutions

$$= -\frac{H_1}{\omega a}\epsilon^{-a\theta} - \frac{H_2}{\omega}\cos\theta + \frac{H_3}{\omega}\sin\theta$$

$$= \frac{dq}{dt} = H_1\epsilon^{-a\theta} + H_2\sin\theta + H_3\cos\theta, \text{ where } a = \frac{R+P}{\omega PRC}$$

$$= K_1\epsilon^{-a\theta} + K_2\sin\theta + K_3\cos\theta$$

ring cut-off period, see figure 8*f*, the circuit equations e,

$$' = Si_S' = \frac{q'}{C}$$

which give

$$q' = h\epsilon^{-b\theta}; \quad i_C' = \omega bh\epsilon^{-b\theta}; \quad i_R' = \frac{h}{RC}\epsilon^{-b\theta}$$

$$i_S' = -i_L' = \frac{h}{SC}\epsilon^{-b\theta}$$

$$b = \frac{R+S}{\omega RCS}$$

$$i_D' = \frac{e}{2S} - i_S'; \quad i_S = \frac{e}{2S} + i_S'$$

Solving for the coefficients results in

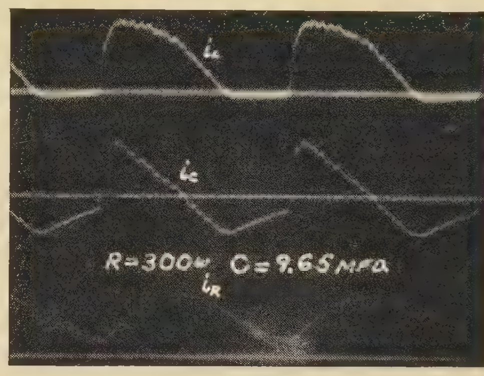
$$H_1 = -\omega aRCK_1; \quad H_2 = -\omega RCK_3; \quad H_3 = -\omega RCK_2$$

$$K_2 = \frac{(R+P)\phi E_m}{(R+P)^2 + (R\omega CP)^2}$$

$$K_3 = -\frac{\omega RCPE_m}{(R+P)^2 + (\omega RCP)^2}$$

$$h\epsilon^{-b\theta_2} = CE_m\sin\theta_2$$

Assuming that the transient term, $K_1\epsilon^{-a\theta}$, is zero at $\theta = \theta_2$, due to high rate of decay as mentioned in the



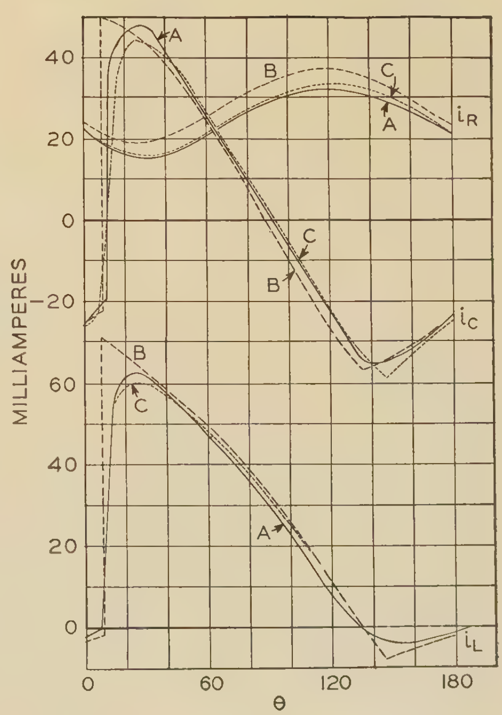


Fig. 9. Comparison with typical case of resistance and capacitance in parallel

A—Oscillogram

B—Perfect rectifier

C—Constant rectifier

R = 300 ohms, C = 9.65 microfarads, E_m = 14.1 volts, ω = 377

method of solution, the condition that $i_D = 0$ at $\theta = \theta_2$, becomes

$$\tan \theta_2 = \frac{\omega RC(\phi RS)}{(\omega RCP)^2 + (R+P)^2 + \phi S(R+P) + \phi SP(\omega RC)^2}$$

which reduces to the perfect rectifier form

$$\tan \theta_2 = -\omega RC$$

for $P = 0$ and $S = \infty$. H_1 and K_1 can now be determined from the boundary conditions that exist at the cut-in angle, $\theta = \theta_1 + \pi$, namely, $i_D = 0$ and $e' = e_L = e$. Next find $K_1\epsilon^{-a\theta_2}$ to see if further revisions are needed, or if that term is negligible as was assumed in finding θ_2.

Figure 9 shows the relation between the wave-forms observed and those obtained from the equations developed here. The first solution was satisfactory since the transient term became very small at θ_2.

Load of Capacitance in Parallel With Resistance and Inductance in Series

The solution of more complicated circuits, especially those having cut-off, becomes rather difficult when treated in general form. In a given numerical case the coefficients and exponents can be evaluated as soon as found, thus reducing the length and difficulty of the computations. A common circuit can be obtained by putting inductance in series with the resistance in the previous case. Figure 8 can be likewise modified to fit this case. The method of solving this case for a constant rectifier is outlined here, and the resulting wave-forms compared with an observed wave-form obtained from a typical case, see figure 10.

Set up the differential equations for the circuits and solve them for the general form of the current equations for both conduction and cut-off periods. These will be in the form

$$i_C = H_1\epsilon^{m_1\theta} + H_2\epsilon^{m_2\theta} + H_3 \sin\theta + H_4 \cos\theta$$

$$i_R = K_1\epsilon^{m_1\theta} + K_2\epsilon^{m_2\theta} + K_3 \sin\theta + K_4 \cos\theta$$

$$i_C' = h_1\epsilon^{n_1\theta} + h_2\epsilon^{n_2\theta}$$

$$i_R' = k_1\epsilon^{n_1\theta} + k_2\epsilon^{n_2\theta}$$

where

$$m = -\frac{R}{2\omega L} + \frac{1}{2\omega PC} \pm \sqrt{\left(\frac{R}{2\omega L} - \frac{1}{2\omega PC^2}\right) - \frac{1}{\omega^2 LC}}$$

$$n = -\frac{R}{2\omega L} + \frac{1}{2\omega SC} \pm \sqrt{\left(\frac{R}{2\omega L} - \frac{1}{2\omega SC}\right)^2 - \frac{1}{\omega^2 LC}}$$

Assuming the transient terms to be zero at $\theta = \theta_2$, and using the condition that $i_D = 0$, the cut-off angle, θ_2, can be determined. The other coefficients can be found by using circuit relations and boundary conditions existing for the problem at hand. Solution of cut-in angle conditions gives the values of θ_1 and the transient term coefficients.

Knowing the transient terms, check back and find a revised θ_2, using the values found above, instead of zero first assumed. If necessary, repeat the computation for the cut-off currents, revising θ_1 and obtaining a second value for the transient terms, and then a third value of θ_2, etc. The number of repetitions necessary depends upon the accuracy desired. For the comparative curves shown in figure 10, 2 revisions were made, but the first produced the greatest change. In many problems it is possible to stop with the first analysis.

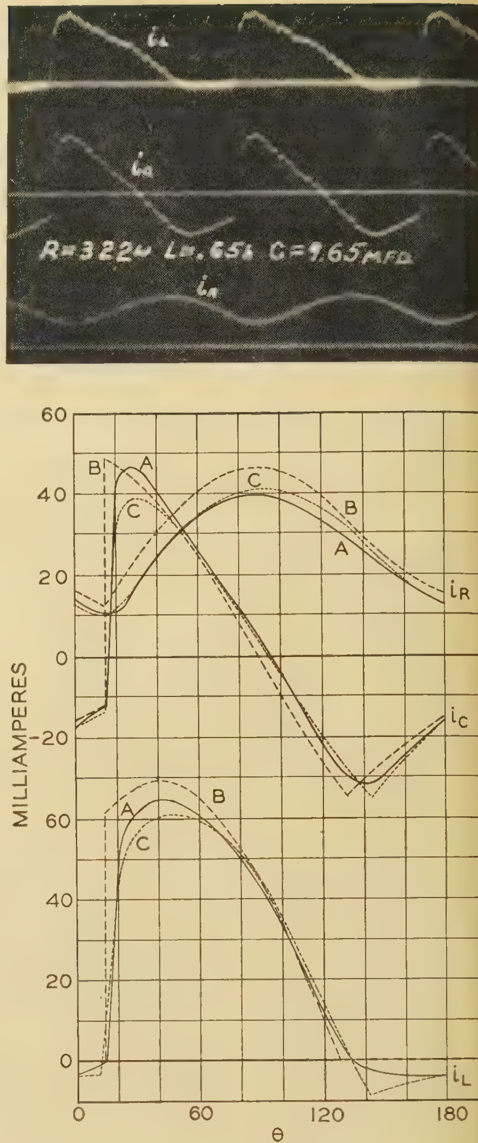


Fig. 10. Comparison with typical case of resistance and inductance in parallel with capacitance

A—Oscillogram

B—Perfect rectifier

C—Constant rectifier

R = 322 ohms, L = 0.65 henry, C = 9.65 microfarads, E_m = 14.2 volts, ω = 377

Conclusion

This paper has presented a useful method of analyzing the behavior of copper-oxide rectifier circuits. The varying resistance characteristic of the rectifier element is replaced by 2 constant resistances, D, effective for direct flow, and S, effective for inverse flow. This approximate representation of the rectifier is called the "constant rectifier."

This approach gives solutions of a highly satisfactory degree of accuracy. Under certain load conditions, there

(*Concluded on pages 366–67*)

fect of Varying Weather Conditions on Energy Required for Traction and Heating of Multiple-Unit Trains

By H. E. PRESTON
NONMEMBER AIEE

'HE HEATING of passenger cars electrically together with the additional energy required for traction purposes when cold weather prevails cause eases in operating expenses which are of great import- e on the Illinois Central Railroad where power is pur- sed.

his article deals primarily with the experience of the iois Central in operating its electrified suburban serv- in Chicago during the past 9 years.

efore discussing the accompanying curves which are ed on average conditions a brief summary of weather ditions in Chicago and data on the Illinois Central ipment follows.

he daily range of temperature for Chicago is 14 de- es between normal maximum and normal minimum peratures. The record minimum is −23 degrees and record maximum is 105 degrees.

he average temperatures for the past 64 years are as ows:

Jan.	Feb.	Mar.	Apr.	May	June	July
24.5	26.6	35.7	47.1	57.4	67.6	72.7
Aug.	Sept.	Oct.	Nov.	Dec.	Year	
71.6	65.3	53.8	40.2	29.0	49.3	

he average hourly velocity of the wind in all directions 1 miles per hour.

he average number of days during the year when the imum temperature is 32 degrees or below is 108.

he average number of days during the year when the imum temperature is 0 degrees or below is 8.

During the past 9 years there have been approximately days each year when heating was used on the cars for east a portion of the day.

here are 280 cars in multiple unit service. All of the s are heated with electric heaters of the enclosed ele- nt type, operating on 1,500 volts direct current, and ipped with thermostatic control set to maintain a tem- ature of 56 degrees Fahrenheit. The cars have ap- ximately 4,500 cubic feet of air space and seat 84 pas- gers. Each car is equipped with 29,500 watts in heat- located under the rattan-covered seats. The motor- n's cab is equipped with a 3,000-watt heater. The s are insulated with hairfelt under the composition rs and 3-ply Salamander applied to the sides and roof ets. Ventilation is provided by monitor sash ventila- s.

During the past 9 years there has been an average of scheduled trains daily except Sundays and holidays, there has been operated an average of 824,000 car es per month.

The average distance between stops including all classes service is approximately 0.96 mile.

During the winter season of 1933 a unit of the equipment, comprising a motor car and a trailer car, was equipped with graphic meters which recorded the operations of the heating relay and the current in the traction motors. Integrating meters were also installed on this unit to measure separately the energy used by the traction motors, the air compressor motor, the motor generator set, and the heater circuits. This specially equipped unit was operated in regular service similar to any of the other equipment and a record kept of the meter readings at the conclusion of each trip together with other pertinent data such as, the class of service rendered by the train, the weather conditions and the position of the cars in the train when consisting of more than 2 cars. Personal observations were made at various times to enable an accurate interpretation of the meter readings to be made.

The energy used for traction will be considered for the purposes of this article as including in addition to the energy used by the motors and their control equipment, the total line loss between substations and trains, the energy used by the air compressors, the energy used by the motor generators on the cars which charge the batteries and supply the lighting circuits, and all other d-c output from the substations excepting energy used for heating of the cars.

The relation between average kilowatt-hours per car mile and temperature is shown in curve A of figure 1 and was drawn from the d-c substation output load records combined with a daily record of the movement of the cars including the car miles operated.

From the information obtained in the above manner it was found that the increase in kilowatt-hours per car mile over the summer requirement commenced at approximately 60 degrees and between 60 and 45 degrees the increase was due entirely to the heating in the cars. In the kilowatt-hours per car mile-temperature curve it will be noted that at 60 degrees the consumption is 4.30 kilowatt-hours per car mile and at 45 degrees it is 4.73 kilowatt-hours per car mile. For this range of temperature of 15 degrees the difference in consumption is 0.43 kilowatt-hour per car mile and the curve is a straight line. This difference is equivalent to an increase of 0.0286 kilowatt-hour per car mile per degree due to the heating of the cars.

Daily records of the train operations included total car miles operated during the morning and evening peak demand hours and also the length of time the cars were in service during these hours, which gave the total number of "car hours" in service. From this information it was found that with the heaters on continuously the maximum

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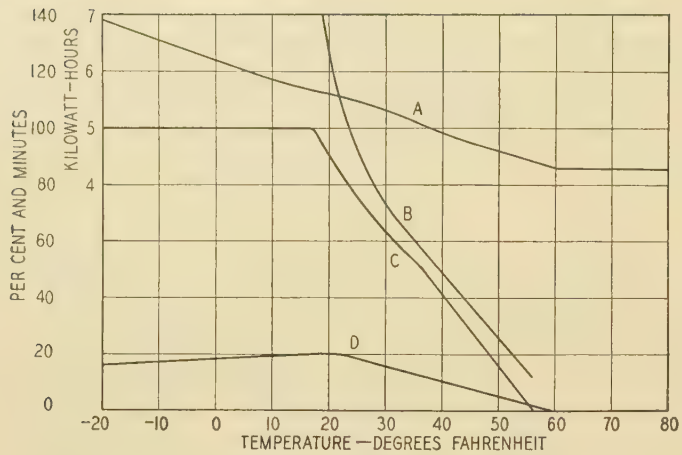

Fig. 1. Curves showing effect of temperature on train heating and traction requirements in suburban service of the Illinois Central system

A—Average kilowatt-hours per car mile

B—Average time in minutes elapsed before thermostat opens heater circuit when heating a cold car in storage yards

C—Per cent of time heater circuit is closed for trains in service and handling passengers

D—Per cent of the total energy consumption due to heating in the cars

possible heating that can be used would increase the consumption 1.13 kilowatt-hours per car mile over the consumption when no heat was being used.

Dividing this maximum possible heating of 1.13 kilowatt-hours per car mile by the increase of 0.0286 kilowatt-hour per degree of temperature obtained above we get a range of temperature of 40 degrees during which the energy for the heating of the cars increases. This increase is at the rate of 0.67 per cent per degree between 60 and 20 degrees. As the heating of the cars commences at approximately 60 degrees this means that at 20 degrees the energy required for heating is constant and at the maximum amount possible.

Curve *C* shows the per cent of the time the heater circuits are closed on trains in service and handling passengers after the cars have been heated previously a sufficient length of time to operate the thermostat if the weather conditions permit. This curve was drawn from the meter records obtained from the specially equipped unit and it will be noted that at approximately 17 degrees the heaters are on continuously.

The above statements regarding heating apply to cars in service.

It has been the practice on the Illinois Central to start heating the cars approximately one hour before departure from storage yards when the temperature is below freezing, and when the weather is more severe this preheating time is increased. When the temperature is colder than 10 above zero it has been found desirable to have the heat on continuously.

The energy required to heat the cars prior to their departure from the storage yards increases materially the average kilowatt-hours per car mile on days when the temperature is below freezing.

Curve *B* shows the elapsed time in minutes between the time the heat is turned on in a cold car standing in the storage yards until the thermostat operates to open the heater circuit.

The ventilation provided in the cars affects the energy consumption necessary for heating. The number of changes of air per hour in the cars is determined by the number of ventilators opened together with the frequency of stops requiring opening of the car doors. It is customary to provide more ventilation in smoking cars than in other cars in the train by opening more ventilators. In colder weather patrons remain inside the heated shelters provided on the elevated platform until the doors of the trains are opened causing congestion by not entering doors of the train farther away from the shelters. This causes longer loading and unloading time at stations which increases the length of time the doors are opened and resulting in the heat being dissipated more quickly.

Considering the heat emitted by the passengers themselves as it affects the energy consumption for heating the cars no definite conclusion could be arrived at. The indications are that the more passengers handled the more often the vestibule and diaphragm doors are opened by the passengers walking from one car to another which increases the ventilation in the cars and offsets the heat gained from the passengers themselves.

At temperatures below freezing it is noticeable that a majority of the passengers will close the doors between the vestibule and the body of the car, whereas, at more moderate temperatures these doors remain opened. This reduces slightly the percentage of the time the heat would be on at temperatures below freezing were these doors not closed and accounts for curve *C* not being a straight line.

After a car has been heated to a maximum according to the prevailing temperature there is considerable heat stored in the heaters themselves as well as other metal parts of the cars. To derive the maximum benefit from this stored heat the operating instructions to the trainmen provide for pulling the heater circuit switches in all cars at specified points before arriving at terminals on those trains that are to be tied up in storage yards. It has been found that no inconvenience is experienced in pulling heater switches from 15 to 20 minutes before arrival at destination. The economy resulting from this practice is worth while especially where it reduces the demand charges.

Referring to curve *A* it will be noted that the summer requirement is constant at 4.3 kilowatt-hours per car mile and starting at 60 degrees the consumption increases in a straight line at the rate of 0.67 per cent per degree to a temperature of 45 degrees due entirely to heating in the cars. Colder than 45 degrees the rate of increase is greater than that required for heating alone, until at 20 degrees above zero the total increase over the summer requirement is 1.3 kilowatt-hours per car mile as compared to a maximum possible increase due to heating alone of 1.13 kilowatt-hours per car mile. This additional increase or difference of 0.17 kilowatt-hour per car mile is due to the fact that these lower temperatures are experienced during

(*Concluded on page 366*)

The Capacitance of a Parallel-Plate Capacitor by the Schwartz-Christoffel Transformation

By HARLAN B. PALMER
MEMBER AIEE

AN EXACT method of calculating the capacitance of a parallel-plate air condenser, taking into account its fringing effect, has been suggested by J. Thomson[1] and more completely worked out by E. H. Love.[2] The purpose of this paper is to promote fa-iliarity with this mathematical technique by making it ore readily accessible to American engineers. In ad-tion to the exact method, a number of approximate ethods are included.

The capacitance of a condenser consisting of a single ir of very long parallel plates in air is usually calculated the formula

$$= \frac{w}{4\pi d} \text{ statfarads per centimeter} \qquad (1)$$

This formula neglects the fringing of the flux and the ix which passes between the back sides of the plates, and nsequently the true value may be several thousand per nt greater than indicated. An error of this magnitude ould occur, for example, if equation (1) were applied to pair of very long thin rectangular bus bars separated by any times their width.

he Schwartz-Christoffel Transformation

The general problem of mapping polygons was first in-stigated by Schwartz[3] and Christoffel.[4] Since numer-s explanations of this general method are available in glish,[5,6] only a brief outline will be included here.

In the map of any electric field, the flux and potential es intersect each other at right angles and, if the scales flux and potential are made equal, the areas formed by e 2 families of intersecting lines are so-called curvilinear uares. If the field map, originally plotted in a complex ane Z, is replotted in a complex plane W, where W is y analytic function of Z, the orthogonal intersections d curvilinear squares will be preserved. The Schwartz-ristoffel transformation consists of finding that particu-functional relationship between Z and W which makes e transformed areas true straight-sided squares. In her words, the change of variable has the effect of warp- the original boundary conditions or electrodes (be-een which the flux and potential lines are unknown rves) into new boundary conditions (between which e flux and potential lines are uniformly spaced straight es) without changing the capacitance. The Schwartz-ristoffel transformation does not determine $Z =$ W) directly, but first determines both Z and W as func-ns of an auxiliary variable ζ.

$$= f_1(\zeta) \qquad (2)$$

$$= f_2(\zeta) \qquad (3)$$

In some cases it is possible to eliminate ζ between equations (2) and (3). In other cases the relation between Z and W must be kept in parametric form.

Z Plane

The ($Z = x + jy$) plane, in which the given boundaries of the parallel-plate condenser are plotted, is shown in figure 1*a*. The Schwartz-Christoffel transformation applies only to those 2-dimensional field problems whose boundaries are the straight sides of a polygon. The boundaries of this problem consist of the 2 plates which are equipotential surfaces, the zero flux line passing between the centers of the inside surfaces of the plates, and the maximum flux line passing (through ∞) between the centers of the back sides of the plates. This figure, resembling a double cross, is virtually a polygon whose sides have collapsed until they are contiguous, as examination of the slightly expanded view in figure 1*b* will reveal.

ζ Plane

The auxiliary ($\zeta = \xi + j\eta$) plane is shown in figure 2. Due to symmetry, only the right-hand half of the Z plane and the upper half of the ζ plane need be considered. The 6 vertices of the Z polygon (lettered *a*, *b*, *c*, *d*, *e*, *f*) may be

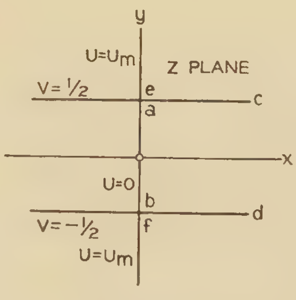

Fig. 1a

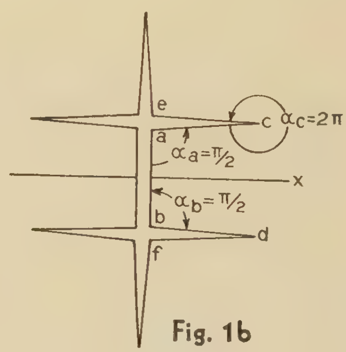

Fig. 1b

transformed into the similarly lettered points on the ξ axis of the ζ plane. Furthermore the extremities of the y axis become the extremities of the ξ axis. Thus the problem has been resolved into finding the capacitance between 2 plates (shown by heavy lines *a-c-e*, and *f-d-b* in figure 2) lying in the same plane and having widths of $(1/k - 1)$ and being separated a distance of $(1/k + 1)$, center to center.

A paper recommended for publication by the AIEE committee on electrophysics. Manuscript submitted August 29, 1936; released for publication November 16, 1936.

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1. For all numbered references, see list at end of paper

W Plane

The ($W = U + jV$) plane is shown in figure 3 and has co-ordinates U (representing flux) and V (representing potential). The area plotted in this plane is a rectangle bounded by the sides ($V = {}^1/_2$), ($V = -{}^1/_2$), ($U = U_m$), and ($U = -U_m$). Thus the problem has been further resolved into finding the capacitance of an equivalent parallel-plate condenser (shown by the heavy lines of figure 3) in which fringing is absent and all of the flux passes with uniform density between the inside surfaces of the plates. Hence equation (1) may be applied. Since the capacitance of this equivalent condenser depends only upon the ratio R of plate width to plate separation, the separation (equal to potential since the potential gradient is uniform) has been arbitrarily chosen as unity, while the width or R (equal to flux) is as yet undetermined.

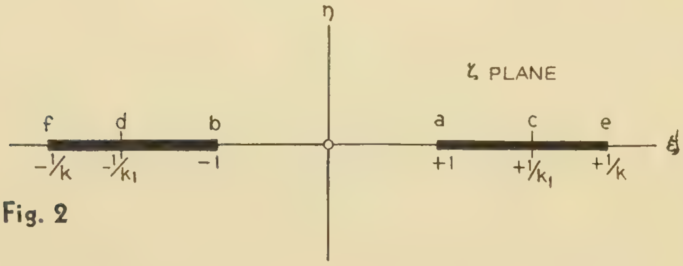


Fig. 2

Transformation Equations

The functional relationship transforming the vertices of any polygon in one complex plane into specified points all on one axis of another complex plane may be found by solving equation (4).

$$Z = A\int[(\zeta - \xi_a)^{m_a}(\zeta - \xi_b)^{m_b}(\zeta - \xi_c)^{m_c} \ldots (\zeta - \xi_n)^{m_n}]d\zeta \qquad (4)$$

The ξ_n's are the co-ordinates of the n points into which the n vertices are to be transformed. The exponents (m_n) are given by $m_n = (\alpha_n/\pi) - 1$, where the α_n's are the angles of the polygon to be transformed. See figure 1*b*.

Transforming from Z to ζ and referring to figures 1*a*, 1*b*, and 2,

$\xi_a = 1$ $\qquad m_a = (\pi/2\pi) - 1 = -{}^1/_2$

$\xi_b = -1$ $\qquad m_b = (\pi/2\pi) - 1 = -{}^1/_2$

$\xi_c = 1/k_1$ $\qquad m_c = (2\pi/\pi) - 1 = 1$

$\xi_d = -1/k_1$ $\qquad m_d = (2\pi/\pi) - 1 = 1$

$\xi_e = 1/k$ $\qquad m_e = (\pi/2\pi) - 1 = -{}^1/_2$

$\xi_f = -1/k$ $\qquad m_f = (\pi/2\pi) - 1 = -{}^1/_2$

$$Z = A'\int\frac{(\zeta^2 - 1/k_1^2)d\zeta}{\sqrt{(\zeta^2 - 1/k^2)(\zeta^2 - 1)}}$$

This is an elliptic integral and may be treated by formula 569, reference (7) to give the result,

$$Z = A[k_1^2E(\phi,k) - (k_1^2 - k^2)\,F(\phi,k)] + C$$

The arbitary constants A and C may be evaluated by inserting the boundary conditions,

$Z = 0$ when $\zeta = \sin\phi = 0$; therefore $C = 0$

$Z = \pm j$ when $\zeta = \sin\phi = \pm 1$; therefore $A = \dfrac{j}{k_1^2E - (k_1^2 - k^2)K}$

$$Z = j\frac{k_1^2E(\phi,k) - (k_1^2 - k^2)\,F(\phi,k)}{k_1^2E - (k_1^2 - k^2)K} \qquad (5)$$

Inserting in equation (5) the additional boundary condition,

$Z = 0 \pm j$ when $\zeta = \sin\phi = \pm 1/k$

the relation, $k_1^2 = k^2\,K'/E'$ results.

For the evaluation of elliptic integrals having upper limits greater than 1, see reference (8), page 43.

Inserting in equation (5) the final boundary condition,

$Z = R \pm j$ when $\zeta = \sin\phi = \pm 1/k_1$

the relation

$$R = \frac{K'E'(\beta,k) - E'F'(\beta,k)}{(E' - K')K + K'E} \qquad (6)$$

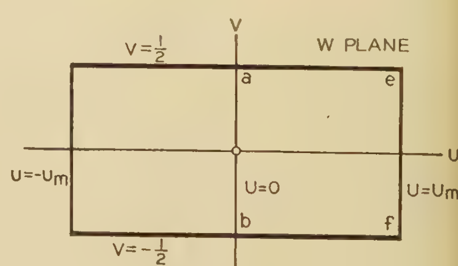
results

where

$$\sin^2\beta = \frac{K' - E'}{K'(1 - k^2)}$$

The combination of complete elliptic integrals in the denominator of equation (6) is identically equal to $\pi/2$, being the celebrated formula of Legendre. For a given value of the ratio R it is impossible to determine k except by trial and error. Values of R have been calculated for

Fig. 3



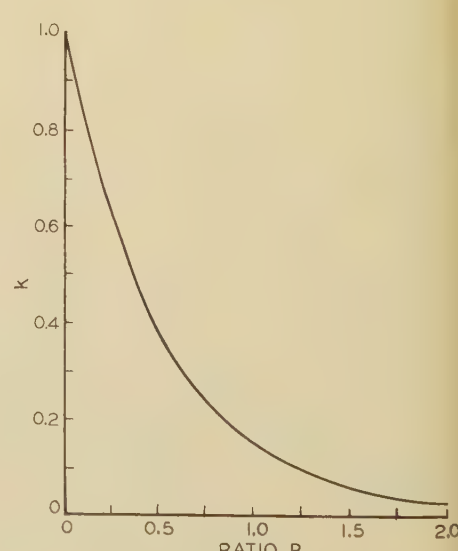


Fig. 4. Equation 6

ny values of k between 0.02365 and 1.0 with the results own graphically in figure 4.

e transformation equation from Z to ζ becomes, after aluating all constants except k which can only be exessed implicitly as in equation (6),

$$= j\, 2/\pi\, [K'E(\phi,k) - (K' - E')F(\phi,k)] \tag{7}$$

Transforming from W to ζ and referring to figures 2 and

$= 1 \qquad m_a = (\pi/2\pi) - 1 = -1/2$

$= -1 \qquad m_b = (\pi/2\pi) - 1 = -1/2$

$= 1/k \qquad m_e = (\pi/2\pi) - 1 = -1/2$

$= -1/k \qquad m_f = (\pi/2\pi) - 1 = -1/2$

$$= B' \int \frac{d\zeta}{\sqrt{(\zeta^2 - 1/k^2)(\zeta^2 - 1)}}$$

$$= BF(\phi,k) + C$$

serting the boundary conditions,

$= 0$ when $\zeta = \sin\phi = 0$; therefore, $C = 0$.

$= \pm j^{1/2}$ when $\zeta = \sin\phi = \pm 1$; therefore, $B = j/2K$

$$= j\,\frac{F(\phi,k)}{2K} \tag{8}$$

liminating ($\zeta = \sin\phi$) between equations (7) and (8),

$$= 2/\pi\, [2(E' - K')KW + jK'E(am - j2KW,k)] \tag{9}$$

alculation of Capacitance

Corresponding to the given ratio R of plate width to ate separation, determine the modulus k from figure 4.

From a table of elliptic integrals[7,9] determine the complete elliptic integral K and the complementary elliptic integral K'.

Since the 2 axes drawn through the origin in figure 3 represent the zero-potential and zero-flux lines respectively, the point e represents half of the total flux and half of the potential difference between plates. The value of ζ corresponding to point e is $1/k$, and $\phi = \sin^{-1} 1/k$. Substituting this value of ϕ in equation (8),

$$\begin{aligned} W &= U + jV = j\,\frac{K - jK'}{2K} \\ U_m &= K'/2K \\ V &= 1/2 \\ C &= U/4\pi V \\ C &= K'/4\pi K \end{aligned} \tag{10}$$

For example: when

$R = 2$
$k = 0.02365 = \sin 1.355$ degrees
$k' = 0.99972 = \sin 88.645$ degrees
$K = 1.571$
$K' = 5.131$
$C = 0.2599$ statfarad per centimeter

By equation (1)

$C = 0.1592$ statfarad per centimeter

Approximate Formulas

1. For very large values of R, there is an approximate formula due to Bromwich and given by Love,[2] as follows:

$$C = R/4\pi[1 + (1/\pi R)(1 + \log 2\pi R)] \tag{11}$$

For a value of $R = 2$, $C = 0.2486$ which is only 4.35% low.

2. Maxwell[11] obtained a result which is quite similar to equation (11) by using condenser plates of semi-infinite extent and investigating the field in the vicinity of the finite ends. This simplifies the transformation from Z to W by eliminating the 4 polygonal right angles at a, b, e, and f in figure 1a and substituting a zero polygonal angle where the plates meet at infinity. Maxwell's result, making certain other simplifications which are justified for large values of R, is as follows:

$$C = R/4\pi\{1 + (1/R\pi)\,[1 + \log(1 + \pi R)]\} \tag{12}$$

3. It has been found that for small values of R (less than one), the capacitance of a parallel-plate condenser is approximately the same as for 2 round conductors having diameters of 1/2 the plate widths and being separated center to center, by the same amount as the separation between the plates. The capacitance in this case is given by

$$C = \frac{1}{4 \log (4/R)} \tag{13}$$

Although no mathematical justification for equation (13) has been discovered, it has been checked against the exact equation at many points and found to be surprisingly accurate.

Capacitances of parallel-plate condensers, for values of R less than 2, have been calculated from equations (1), (10), (11), and (13). The results are shown in figure 5.

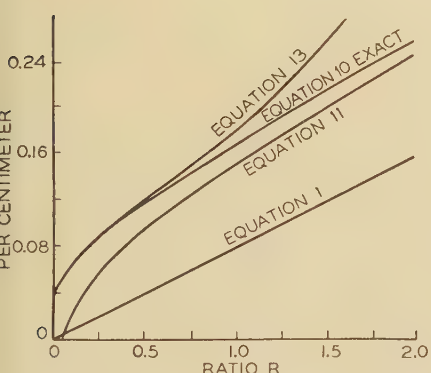


Fig. 5

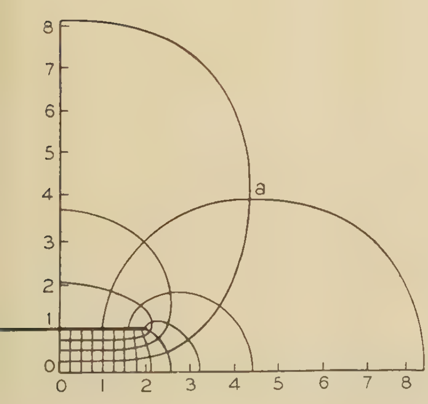


Fig. 6. Map of electric field of parallel - plate capacitor

Field Map

The Schwartz-Christoffel transformation, in addition to supplying an exact method for the calculation of the capacitance of a parallel-plate condenser, makes it possible to map the entire electric field. One quadrant of the field map, for $R = 2$, is shown in figure 6. The points of intersection of the flux and potential lines were calculated from equation (9). The increment for both flux and potential is $^1/_8$. There are 4 potential tubes and approximately 13 flux tubes, making the capacitance

$$C = \frac{13}{(4\pi)\,4} = 0.2599 \text{ statfarad per centimeter.}$$

Any intersection such as point "a" in figure 6 may be calculated as follows:

$k = 0.02365$ (See figure 4)
$k' = 0.99972$
$K = 1.571018$
$K' = 5.131306$
$E = 1.570579$
$E' = 1.001295$
$U = U_m - 1/8 = K'/2K - 1/8 = 1.50812$
$V = 1/8$
$F(\phi,k) = 0.3927 - j4.7386$ (equation 8)
$F(\phi,k) = 0.3927 + j0.3927 - jK'$

$$\sin\phi = \frac{1}{ksn\,(0.3927 + j0.3927)} \qquad sn\,(u \pm jK') \equiv \frac{1}{k\,sn(u)}$$

$\sin\phi = 56.5048 - j50.9732$ reference (10) equation 760.1
$E(\phi,k) = 1.5375 - j5.1456$ reference (8) pages 33, 34, 83
$Z = 4.37 + j3.99$ equation (9)

Symbols Used in This Paper

C = capacitance
w = semiplate width
d = semiplate separation
R = ratio of plate width to plate separation
Z,W,ζ = complex variables
x,y = co-ordinates of Z
U = co-ordinate of W denoting flux
V = co-ordinate of W denoting potential
ξ,η = co-ordinates of ζ
A,A',B,B',C = constants of integration
α_n = angle of polygon in Z plane
a,b,c,d,e,f = vertices of polygon in Z plane
k_1 = arbitrary constant
k = modulus of ellipitc integrals
k' = complementary modulus = $\sqrt{1-k^2}$
$sn\ u$ = elliptic function
$F(\phi,k)$ = elliptic integral of first kind
$E(\phi,k)$ = elliptic integral of second kind
K = complete elliptic integral of first kind
E = complete elliptic integral of second kind
K' = complete complementary integral of first kind
E' = complete complementary integral of second kind.

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Effect of Weather Conditions on Energy Required for Multiple-Unit Trains

(*Continued from page 362*)

the winter months when due to reduced hours of daylight an increased amount of lighting is used in the cars, the air compressors also do more work as the temperature lowers and in addition to this is the fact that inclement weather increases the standing time at stations requiring more traction energy to be used to maintain schedules.

Between 45 and 20 degrees the increase in kilowatt-hours per car mile due to traction which includes all auxiliaries, etc., other than heating appeared to be made up entirely of the above mentioned causes and there was little indication that increased bearing friction or wheel flange resistance entered into it.

Proceeding along the curve A it may be assumed that at temperatures below 20 degrees any further increase in kilowatt-hours per car mile is due to traction and auxiliaries other than heating. Commencing at 20 degrees and colder the traction energy increases at the rate of 0.75 per cent per degree expressed as a per cent of the summer requirement.

Assuming that the energy required for heating increases at a uniform rate to the point where it is constant and at a maximum, the per cent of the total energy consumed which is due to heating may be calculated and this result is plotted as curve D. The difference between curve D and 100 per cent is the percentage of the total energy used for traction and auxiliaries other than heating.

An Analysis of Copper-Oxide Rectifier Circuits

(*Continued from page 360*)

is noticeable departure in wave form between the real rectifier and the approximation, as shown by the nonsinusoidal shape in figure 5a. However, in these cases, the assumption of a constant rectifier is a decided improvement over that of a perfect rectifier.

An equivalent circuit was established for this constant rectifier and its application to various types of loads discussed. A few standard circuit analyses were presented and the resulting computed wave-forms compared with observations. Thus this paper presents a method of obtaining the current forms present in a rectifier circuit,

ich yields better results than the perfect rectifier alization and yet is not much more difficult to use. using the equivalent circuit as developed in equation nd shown in figures 4 and 8, the series method outlined Stout[6] can be applied to the constant rectifier circuits.

st of Symbols

= equivalent rectifier resistance to current in the direction Cu_2O to Cu

= equivalent rectifier resistance to inverse currents

$= \frac{2DS}{D+S}$, analogous circuit constants to replace constant rectifier in determining i_L

$= \frac{S-D}{S+D}$

= impedance of bridge with d-c terminals open

= impedance of bridge with d-c terminals shorted

= $E_m \sin\theta$, applied voltage, ($\theta = \omega t$)

= load voltage during conduction

= load voltage during cut-off

= condenser charge during conduction

= condenser charge during cut-off

= $i_R + i_C$ total load current during conduction

i_R = resistance branch current during conduction

i_C = condenser branch current during conduction

i_L', i_R', i_C' = currents during cut-off

i_D = current through bridge leg acting as D

i_S = current through bridge leg acting as S

i_S' = current through bridge legs due to e'

i_a = total line current

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Discussions

f AIEE Papers—as Recommended for Publication by Technical Committees

N THIS and the following 3 pages appear discussions submitted for blication, and approved by the technical committees, on papers presented the general technical sessions of the AIEE South West District meeting llas, Texas, October 26–28, 1936. Authors' closures, where they have been bmitted, will be found at the end of the discussion on their respective papers. Members anywhere are encouraged to submit written discussion of any per published in Electrical Engineering, which discussion will be reewed by the proper technical committee and considered for possible publican in a subsequent issue. Discussions should be submitted to C. S. Rich, cretary, technical program committee, AIEE headquarters, 33 West 39th reet, New York, N. Y.

Disturbance Duration Recorder

cussion of a paper by C. H. Frier published the September 1936 issue, pages 1025–8, presented for oral discussion at the gen- technical session of the AIEE South st District meeting, Dallas, Texas, October , 1936.

K. Honaman (Bell Telephone Laboraies, Inc., New York, N. Y.): Mr. Frier's per offers an ingenious scheme for making a record of time durations of the order of magnitude of those ordinarily involved in voltage surges. As the author has pointed out, the ability to measure and record intervals of the order of magnitude of a few cycles to a few seconds is, particularly in certain cases, very desirable. It may be of interest, therefore, to present an alternative method for making such records which engineers interested in this problem might find helpful.

The possibility of initiating the operation of the recorder by means of an electron tube control instead of the contact-making voltmeter is one which suggests itself and is recognized by the author in the paper. Such a device would have the advantage not only of additional speed in operation to avoid part of the delay of 1 to 3 cycles inherent in the contact-making voltmeter, but also would be more rugged.

An arrangement for accomplishing this could be set up by means of tubes rectifying the 60-cycle current from the power line using the d-c output against a bias to trigger an electron tube with a relay in the anode circuit. Such an arrangement would necessitate the use of a resetting circuit for the tube but means of accomplishing this are available. A vacuum tube with a marginal relay operating in its plate circuit has also been suggested.

In the recording of the duration itself, another scheme, the principle of which has been suggested by Mr. L. K. Swart, is worth consideration. This depends upon the relationship between the voltage across the terminals of a condenser and the time during which the condenser has been charged. The practical working out of the suggestion is accomplished by having the initiating device, whether it be a contact-making voltmeter or electron tube trigger arrangement, connect a capacitor of appropriate size in series with a charging battery and a resist-

ance at the beginning of the period whose duration is to be measured. The size of the capacitor and the resistance and the voltage of the battery are so proportioned that the condenser will not be fully charged for the maximum interval to be measured. At the end of the interval the capacitor is disconnected from this circuit and switched by means of a relay to the grid of a high-impedance vacuum tube, in the plate of which is inserted a graphic voltmeter. The leakage can be made sufficiently small so that the graphic voltmeter swings to a point corresponding to the voltage of the capacitor which, in turn, bears a definite relation to the time interval during which it has been charged. Thus the graphic meter can be made to indicate the time at which the surge took place and by means of its deflection, the duration of the disturbance. The deflection would be calibrated in units of time. By means of electron-tube circuits and fast relays the delay in connecting and disconnecting the capacitor and the charging circuit can be made as low as the order of $^1/_2$ cycle (0.008 second).

If, in such an arrangement the charged capacitor were left connected to the grid of the low-leakage vacuum tube, the graphic meter would continue to read for a considerable period, this reading falling off slowly as the leakance of the circuit discharged the condenser. This falling off can be made so slow that the voltage will be reduced only a negligible amount in a minute. It is only necessary to maintain the charge long enough to permit the graphic meter to record the deflection, and relay circuits would be arranged to short circuit the capacitor after a sufficient interval has elapsed to give a satisfactory deflection. This interval can be arranged to suit the characteristics of the graphic meter itself.

It should be noted that the ability of this instrument to measure successive surges would depend upon the rate at which the graphic meter chart is moved. It could not differentiate between surges closer together than the time interval required to move the paper a distance sufficient to separate the pen traces.

Electrical Features of the
Texas Centennial Central Exposition

Discussion and author's closure of a paper by John Fies published in the October 1936 issue, pages 1060–74, and presented for oral discussion at the general technical session of the AIEE South West District meeting, Dallas, Texas, October 26, 1936.

C. M. Cutler (nonmember; General Electric Company, Cleveland, Ohio): The architecture is modern in character but still reflects some of the feeling of the old Spanish missions of Texas. The texture of the wall surfaces is similar. The effect depends principally upon mass, form, painted decoration, and sculpture. The fact that the majority of the buildings are to be used for subsequent state fairs and regional expositions made it desirable to use a method of illumination which would allow the equipment to be removed during the time the exposition is not in use and store it. The lack of maintenance and protection during the large part of the year when the buildings would be unoccupied made it rather impractical to use many of the newer forms of architectural elements, such as recesses, panels of translucent materials, etc., except in a few cases. Consequently, the logical method of illumination is principally floodlighting with the units located in specially designed pits, concealed behind landscaping, installed in setbacks, or placed in towers. In all cases however, lighting was particularly designed for each building.

W. E. Folsom (nonmember; Dallas Power and Light Company, Dallas, Texas): Interior lighting in Centennial areas of important buildings uses on the average, over 4 watts per square foot. This is in a combination of indirect and controlled direct lighting systems—the latter in the form of recessed reflectors with either flush louvers, silver-bowl lamps, or diffusing glass panels. Louvers are of either concentric or geometric types designed in general with light cut-off of about 30 degrees from vertical. Silver-bowl lamps are effectively used in shallow recessed reflectors with comparatively wide openings. The several thousand reflectors used in exposition areas are for the most part of special design, spun of aluminum with etched or specular reflecting surfaces made lasting by the Alzak treatment. Reflector units are of 5 general types with a large variety of assemblies possible and providing desirable interchangeability.

The effectiveness of the many types of interior and exterior lighting units was not left to chance—but tested in a lighting laboratory established for the purpose. Spectacular effects were experimented with thoroughly before final designs were determined.

G. M. Buchanan (nonmember; General Electric Company, Dallas, Texas): The absence of windows in the exhibit buildings is worthy of comment. An inspection of the Centennial in the daytime will reveal the desirable artificial lighting in the exhibit buildings. A much more pleasing effect is secured by all artificial lighting than could be secured by a combination of varying daylight and artificial lighting.

Mr. Fies stated for interior lighting 2 to 20 watts per square foot is used, giving a maximum of 40 foot candle. Some of you, not directly concerned with the application of good lighting, may not realize what this means in view of the fact that most of the lighting is indirect. You note the desirability and excellent lighting jobs on the interior of the exhibit buildings.

I want to call your attention to the 870 kw of mobile colored lighting on "Esplanade of State." This is an outstanding installation and the night show place on the Centennial grounds. A national expert in exposition lighting remarked as he viewed the "Esplanade of State" at night—"this, in my opinion, has never been equaled in any installation." I have often been asked how it is that the tower on the Federal Building is so evenly illuminated from top to bottom. The answer is 8 watts per square foot as mentioned in Mr. Fies' paper. The average intensity is 50 foot candle which is so high for floodlighting that any variation in intensity from top to bottom is not noticeable.

The parapet on the Ford Building has 15 watts per square foot or approximately 100 foot candle and is visible a great distance at night. In the Ford Building the daylight effect secured by the combination incandescent and mercury lamps used for the interior lighting is very interesting. The permanent street lighting system as installed by the city and exposition is unusual in that it is economical to maintain, yet has an entirely different appearance from the conventional street lighting standard, and this feature is particularly desirable in expositions. An opportunity to view the exposition grounds from a distance at night will show the desirable effect created by the battery of 24 36-inch searchlights. These searchlights make the exposition visible from a great distance at night and with the color screens offer a suitable climax to the lighting system when viewed from inside the grounds.

R. W. Roessler (Westinghouse Electric & Manufacturing Company, Dallas, Texas): The author is to be commended on his most interesting paper on the electrical features of the Texas Centennial Central Exposition. The exterior and interior lighting of all the buildings within the Centennial grounds definitely proves that full co-operation between the illuminating engineer and the architect is essential; and in this case, resulted in an outstanding lighting spectacle.

Illumination of the streets and grounds of the expositon indicates that careful study was given to provide adequate lighting and still blend in with the building architecture and other surroundings. It is interesting to note the clever manner in which the different street and grounds lighting fixtures were designed and placed, eliminating clashing effects. The lighting and power distribution system of the Centennial Exposition in itself shows thoughtful planning and good engineering. The magnitude of this system can only be realized when we note that the demand varies from 8,200 to 9,000 kw and that the system handles approximately 2,600,000 kilowatt-hours per month. The type of load served, the importance of uninterrupted service, and all other demands on this system are even more exacting than those of a fair sized municipality requiring the same kilowatt demand.

A. E. Allen (General Electric Company, Dallas, Texas): There is one point that seems worthy of additional emphasis, and that is the figure of 1.5 watts per square foot connected load for the entire exposition. This may not seem very much, but it is greater than for any previous world's fair. Some of this increase may be attributable to the large use of air conditioning by the major exhibitors, but lighting did not suffer by diversion of current for air conditioning, for this exposition, in my judgment, is outstanding in its lighting effects. Chicago's Century of Progress was remembered for its extensive use of gaseous tube lighting, and the Texas Centennial Exposition may be remembered for its large scale of mobile color lighting. The combination of the electronic valve with saturable core reactors makes possible a perfect control for blending

nd changing color effects. The huge ower loss formerly experienced in the use f resistance dimmers is avoided, and the ontrol is so flexible that the colors may be hanged without reducing the intensity of ght on the building. The colors may be ixed to produce lovely pastel shades, and lended into innumerable combinations, or rimary colors used as desired. There is ttle doubt that an even greater use of obile color lighting will be made in the xpositions planned for New York and for an Francisco in 1939.

I. C. Hughes (Texas Agricultural and Iechanical College, College Station): Unss I am mistaken, I believe that the inandescent electric lamp was not used at e Paris Exposition of 1881. I wonder hether or not Mr. Fies, in this connection, as referring to arc lights as incandescent ghting rather than the Edison carbon lamp hich was generaly referred to as incanescent lighting. According to my informaon, illumination at the Paris Exposition f 1881, in so far as it was electrically lighted, as produced by the arc lamp.

If I am mistaken in this matter, I should ke very much to be corrected, because it eems to me that the history of the early ses of light should be kept as straight as ossible.

ohn Fies: These discussions, in the uthor's opinion, are all well founded and ontribute materially to the value of the aper. The author herewith expresses his ppreciation of all discussions submitted nd offers the following comments as a osure to the discussions.

In Mr. Cutler's discussion reasons for e types of lighting and architecture are entioned. These reasons should be of articular interest to those who may beome associated with this field of lighting. Ve regret that space in the paper did not ermit details of the interesting engineering roblems.

In Mr. Folsom's discussion it is pointed ut that the lighting as seen at the Exposion has proved to be a definite stimulus to e lighting business, particularly within e area of less than a day's ride from Dallas. his is important. It is a challenge to the uilders of future fairs to provide lighting f types that will afford such a definite imuli.

In Mr. Buchanan's discussion, reference made to artificial versus natural light. Ve find some natural light on the Natural esource Exhibit in the Transportation uilding at the Exposition. This is an xcellent exhibit but an illumination man viewing it is well aware of how much more fective it would have been had it been esented in artificially lighted cases. No iticism is offered, as this exhibit is a rearkable exhibit, assembled quickly, and nsequently was too late to be incorporated the lighting plans.

In Mr. Roessler's discussion, reference as made to the importance of uninterrupd service. The local power company was ven the responsibility of providing reble electric service to the 38 points of livery. From the beginning of the Fair to date there have been no primary interruptions of consequence. When we consider that all branch secondary feeders have their source at the mentioned points of delivery it becomes evident that if primary service is reliable then practically all service is reliable and troubles are necessarily restricted to small circuits and small areas. There have been, to date, no complaints relative to continuity of electric service.

e. In Mr. Allen's discussion, reference is made to the figure 1.5 watts per square foot. This figure is conservative and is based upon gross area. If we exclude from our figures certain areas used for stables for Cavalcade horses and for storage of miscellaneous material, that is, areas not accessible to visitors to the Exposition, we would have to propose a figure in excess of 2 watts per square foot for 145 acres.

f. Professor Hughes is his discussion mentioned that my reference to the use of incandescent lamps at the Paris Exposition in 1881 might be questioned. The author agrees with Professor Hughes that such a statement should be further supported when it pertains to past history and when it may not agree with generally accepted information on the subject. It may have been better had the paper stated that the incandescent lamp was "shown on a relatively large scale" rather than "used," yet the showing may also have constituted the using although the arc light was undoubtedly used extensively. The statement used in the paper was based upon a paragraph found in a very excellent and carefully written book "Electricity at the Columbian Exposition" copyrighted in 1894 and written by John P. Barrett, Chief of Department (probably electrical), Columbian Exposition, Chicago, 1893. It is reasonable to expect that Mr. Barrett had assembled by 1893 considerable authentic information relative to the use of electricity at expositions prior to that date, hence, we owe him our confidence in the credibility of the statement contained in his book as follows:

"Between 1878 and 1881 so many improvements had been made in the utilization of the electrical current for lighting purposes, and so great was the public interest in the subject, that the ever memorable electrical exposition of 1881 was held at the Palais de l'Industrie. It was then that incandescent lighting was first shown on anything like a large scale, and formed with the telephone the chief element of success for that exposition. Arc lighting was also indulged in commercially."

Experiences With a Modern Relay System

Discussion and author's closure of a paper by G. W. Gerell published in the October 1936 issue, pages 1130–6, and presented for oral discussion at the general technical session of the AIEE South West District meeting, Dallas, Texas, October 28, 1936.

Robert Treat (General Electric Company, Schenectady, N. Y.): This paper brings out very convincingly the great value of records obtained by means of an automatic oscillograph to an operator who is determined to keep his system in the pink of condition, so to speak, without at the same time incurring large and unjustifiable expenditures. The many ways in which oscillographic records of accidental system disturbances can be of value to the operator, may roughly be classified into 5 groups.

1. Continuing Check on the Timing and Correct Operation of Relays and Circuit Breakers

Early in our studies of power system instability, it became apparent that a major improvement in stability could be obtained at relatively low cost by keeping the duration of short circuits to a minimum. As a result, high-speed clearing of faults began to be used on new projects; and many existing breakers and relays were speeded up in order to improve system performance during transients caused by short circuits. It was realized that if the stable operation of the system were to depend on high-speed clearing of faults, it would certainly be very desirable that the operator should have available a means for knowing absolutely that faults were actually being cleared in the expected times. There was no way of being sure that relays and breakers would perform in the same way during accidental short circuits that they did during periodic tests of individual devices. Hence it appeared desirable to secure a check on breaker and relay performance during actual operation. The time intervals which it was necessary to measure were very small, since the entire short circuit might last only 6–8 cycles. The only solution seemed to be an automatic oscillograph which should be capable of starting its record at the very beginning of a short circuit.

With some misgivings on the part of the commercial department, the General Electric Company undertook the development of such an oscillograph. The general specifications were in part as follows:

a. It must be capable of being put into operation automatically by a system disturbance.

b. It must furnish a clear, usable record, which began within 1/2 cycle of the incidence of the short circuit.

c. It must run for an adjustable predetermined time, but it must continue in operation if the initiating cause still existed at the end of that time.

d. It must be so designed as to obviate the necessity for changing the film or paper after each record was made; but it must also be possible to remove each record immediately if desired.

e. It must be so simple to operate, adjust, and maintain that it could be installed in power stations and substations, and operated and serviced by men who had no previous experience with oscillographs.

f. It must be priced so that operators would feel that they could afford to use it.

All these specifications were met. Although this device was not put on the market until early in the depression, nearly 50 of them made by one manufacturer alone are now yielding useful and valuable information of accidental system disturbances such as described by the author of this paper.

2. Evidences of System Instability, and of the Appropriate Remedy

Oscillograms of system disturbances are helpful in indicating any tendency of the system to become unstable during or subsequent to accidental faults. Since the likelihood of instability increases with system load, this should be very important now that

utility loads are again increasing so rapidly. When it becomes necessary to bolster up the system stability, oscillograms of part disturbances will often yield valuable information which aids greatly in making an intelligent decision as to which remedial measures will be the most effective per dollar of expenditure.

3. Check on Stability Calculations

Many calculations have been made of the probable performance of systems from the stability standpoint. Although the background of this phenomenon is now well understood, and the results of stability calculations made today contain little of the guess work which entered the computations made even as recently as 7 or 8 years ago, it is still desirable to obtain a check on the assumptions and calculations. Checks obtained by means of staged tests are not altogether satisfactory for the reason that it is undesirable that these tests should cause disturbances to service. This necessitates their being made, if at all, under artificial conditions (such as during light load or with considerable reserve generating capacity connected) which seldom, if ever, exist during normal operation. Oscillograms of accidental system disturbances, however, yield data which serve as a very satisfactory check on the results of stability calculations. Obviously a complete check cannot be obtained from any one disturbance and it is necessary to accumulate the data over a considerable period in order to get a fairly complete comparison of predicted with actual performance.

4. Information Concerning the Values and Phase Positions of the Voltages and Currents of the 3 Phases, and Concerning the Sudden or Momentary Changes in These Values

Practically every relay engineer is occasionally faced with seemingly inexplicable misperformance of his relays. Sometimes relays do not trip when they should; more frequently they trip when apparently they should not. Subsequent tests of the offending devices frequently reveal no reason for their apparent misbehavior. As pointed out by the author of this paper, the automatic oscillograph shows that the currents and voltages in individual phases sometimes jump around in magnitude and phase position during faults and subsequent breaker operations in a most unexpected and apparently erratic manner. From this information it is learned that some of the apparently incorrect relay operations were, in reality, absolutely correct under the conditions which existed; but that the conditions themselves were entirely different from those contemplated when the relay application was made. While this may be of only academic interest when the relay engineer has to explain to his boss why the relaying went haywire, it is of far more than academic interest when he has to decide what ought to be done about it.

5. Reduction in the Time of a Patrol Crew in Locating a Flashover After an Outage

Even though a line successfully returns to service immediately, some operating companies make a patrol after every outage, in order to determine whether the damage is sufficient to require maintenance at some convenient time. As pointed out by the author of this paper, his company and some others have found that it is possible from the information on the oscillograms to determine very closely where the failure occurred, and thus save much time of the patrol crew. Although the author gives no indication of the saving in patrol expense resulting from this practice, it is suspected that this item alone, which was quite unforeseen when the development was first undertaken, is sufficient to justify an automatic oscillograph. If this be true, all the other advantages are obtained for nothing.

Some companies have found that the damage from any single flashover is so slight that they do not feel warranted in patroling a line after each interruption; rather, a thorough inspection is made at the end of each season. It seems entirely probable that if these companies had this means of sending the patrol crew right to the point of flashover, they would feel justified in availing themselves of the additional security of an inspection after each line outage.

The prominence given to the value of oscillograms of accidental system disturbances in this paper is indeed gratifying to one who was partially instrumental in encouraging the original development, and who has strongly felt that the information yielded by an automatic oscillograph was worth far more than its cost. Although many companies which have not yet installed automatic oscillographs are inclined to look upon them as luxuries, which, however desirable, can ill be afforded when they can hardly get money enough for necessary bread and butter, I do not know of a single operating company which has ever bought an oscillograph, that could be induced to part with it for several times the price paid, if it could not be replaced. I suppose the psychology is the same as with an electric refrigerator, or an automobile—it is a luxury until you get your first one; after that, it is a necessity which you are ever after at a loss to understand how you did without, so long.

G. W. Gerell: Concerning Mr. Treat's remarks it might be noted that automatic oscillographs, as available today, are quite reliable, and in general do meet the specifications which he imposed.

In regard to system instability, records obtained from the oscillograph have shown definitely that a number of incorrect operations have resulted from instability and have further indicated remedial steps necessary in the relay equipment to prevent its repetition.

It may be well to mention here that the case of trouble described in connection with the oscillogram of figure 3 of the paper was included, to open up this important subject of, "how fast a relay may operate and still give a correct tripping impulse." It is suggested that considerable thought should be given to this.

As Mr. Treat mentions, the location of line faults from data supplied by the oscillograph has been of great assistance to the patrol crews. But, it will not necessarily reduce patrol expense, inasmuch as the patrol crews cannot be reduced in number. In many instances patrol crews have inspected a line, finding nothing. Later the location was given them from the data secured from the oscillograph. A second patrol was invariably successful.

Steinmetz Painting Presented to High School

An oil painting of Doctor Charles P. Steinmetz (A'90, M'91, F'12, past-president, deceased October 26, 1923) has been presented by the General Electric Company to a new $3,000,000 high school in Chicago, Ill., that has been named for the scientist. The painting shows Doctor Steinmetz at his desk about 3 months before his death, and is the work of H. M. Mott-Smith. It was presented by E. W. Allen (A'03, F'22) vice-president of the General Electric Company, who is shown at the extreme left with Mayor Edward J. Kelly of Chicago at his side. At the right is Daniel F. O'Hearn, principal of the school, and Theodore Luga, a student and son of an immigrant, who accepted the gift for the school.

News

Of Institute and Related Activities

The Institute's 1937 Winter Convention

ERMED by President A. M. MacCuteon, "one of the busiest, most stimulating, d most interesting" conventions that he d ever attended, the Institute's 1937 nter convention drew to a close with a tal registration of 1,165. Perhaps one of e busiest attendants at the convention as President MacCutcheon himself. An usually large number of committee eetings was held, and for the first time the ard of directors met on 2 successive afterons during convention week.

Details concerning registration and atndance are given in the accompanying bulations. Although the total registraon was somewhat less than last year's total, e attendance at various sessions and tivities was good and in some cases exeded last year's attendance. The drop registration, as may be noted from an companying tabulation, was primarily nong those from the New York Section rritory for which the registration was less than last year. Another interesting ct, shown by another tabulation is that e attendance at the smoker, which is lieved to have set a new record, was gher than the number registered. This evidence of the fact that many attended e convention who did not register, so that e actual total attendance was somewhat gher than the registration figures show.

Details concerning the various features the convention are given in the following ragraphs and on subsequent pages.

H. S. Osborne, chairman, technical program committee, speaking on the technical sessions at the opening session of the convention. Seated on the platform, left to right, are Director R. W. Sorensen, of Pasadena, Calif.; President A. M. MacCutcheon of Cleveland, Ohio; H. R. Beardsley of Brooklyn, N. Y., chairman of the winter convention committee; and A. G. Oehler, chairman of the New York Section

OBLE PRIZE PRESENTED AT OPENING SESSION

The convention was officially opened at p.m. on Monday, January 25, by C. R. eardsley, chairman of the general winter nvention committee, who extended a very rdial welcome to all those attending. ollowing his remarks, President Macıtcheon announced that the Alfred Noble ize for 1936 had been awarded to Abe lles, instructor in electrical engineering at e University of California, Berkeley, and unselor of the Institute's University of alifornia Branch. (Details of this award and a biographical sketch of Doctor Tilles appeared in the news pages of the January issue.) President MacCutcheon outlined briefly the details of the award and sketched the recipient's career.

In Doctor Tilles's absence, the prize was presented to R. W. Sorensen, professor of electrical engineering at the California Institute of Technology, Pasadena, and a director of the AIEE, who accepted it in behalf of Doctor Tilles.

PRESIDENT MACCUTCHEON'S ADDRESS

Following presentation of the Noble prize, Chairman Beardsley introduced President MacCutcheon, who spoke on the subject "The Challenge of 1937." In this address, President MacCutcheon amplified his message to the membership published in the February issue. He emphasized particularly the importance of increased activity on the part of the Sections and Branches during 1937, urging that each Section appoint at least one technical committee. "Such Section technical committees," he said, "can develop subjects of unusual interest, and recommend authors of unusual ability, reporting to the national technical committee having jurisdiction. Among our membership are many potential authors who would be willing to devote their time to the preparation of a paper desired by the profession and asked for by fellow Section members. Such papers, when published, would be accompanied by proper recognition to the Section submitting the paper. By this means the technical activities could be made more widely representative, and more fully meet the desires of the membership.

"I feel that the Institute has reason to be truly proud of the fine work being carried on through the Branch organization, but still more can be accomplished in 1937. With the young men in the Branches lies the future of the profession and the future of the Institute. . . .

Concerning the movement under way to broaden the activities of the Institute, President MacCutcheon said: "In 1936, many devoted Institute members, several special committees, and the board of directors have canvassed possibilities in connection with broadening the scope of Institute activities. Should papers be prepared and presented dealing with the relations of the engineer to society, with the engineer's relation to war, with the engineer's relation to the distribution of electrical products, with the engi-

Analysis of Registration at 1937 Winter Convention, New York, N. Y.

assification	Dist. 3	Dist. 1	Dist. 2	Dist. 4	Dist. 5	Dist. 6	Dist. 7	Dist. 8	Dist. 9	Dist. 10	Totals
embers	532	190	178	17	35	2	10	7	1	14	986
en guests	40	9	11	1	2		1			1	65
omen guests	48	21	23	3	1		1			2	99
udents	9	2	4								15
Totals	629	222	216	21	38	2	12	7	1	17	1,165

neer's relation to unemployment, with the engineer's relation to natural resources? Personally, I feel that there should be a sane and intelligent broadening of our activities, provided that in so doing we are following the fundamental principles for which the society was organized. . . ."

He closed by urging "each member . . . to join with the vice-presidents, the other directors, and myself, in the resolve to do all in our power to meet the inspiring challenge of 1937."

Doctor Osborne's Remarks

Following President MacCutcheon's address, H. S. Osborne, chairman of the Institute's technical program committee, spoke as follows on the technical sessions of the convention:

"In preparation for such a convention as this, the technical committees and the technical program committee consider the whole wide range of the professional activities of Institute members. From the various suggestions which are developed by this review a program is adopted, based upon the combined judgment of these committees regarding what at the moment will be of greatest interest and value.

"One feature of this convention, as well as other recent conventions, to which I should like to call your attention is the technical conferences. As you will note there are 4 of these on the present program. The technical conference might be defined as a meeting without the publication of papers. Since these conferences involve very little expenditure, it would be practicable to hold a large number of them in connection with our conventions if they are desired by the membership. Many such conferences might lead up to the future publication of papers summarizing the outcome of the conference or of a series of conferences. The appearance of these conferences on the program is an illustration of the fact that the technical program committee is experimenting with new methods of expanding and enriching the technical activities of the Institute.

"The fact is that the field of activity which is described in our Constitution as "the theory and practice of electrical engineering and of the allied arts and sciences" is rapidly growing. As a result of this vitality it is natural that there should always be a problem of how best to meet the varied interests and desires of the Institute membership. It has been suggested that some members would like to see more attention given in Institute programs to subjects of broad general interest, particularly to subjects in which engineering and the social sciences are both involved. Also, we know that some members would like to have more opportunity for discussion at the Institute meetings of specific subjects on the frontier of technological advance. While such subjects from their nature would often, taken individually, be of immediate interest only to a relatively small number of members, taken in the aggregate they may be of interest to a large number.

"These considerations illustrate the desirability of a careful review of the Institute program having in mind the wide scope of interest of the Institute membership and also the limitations in the amount of money which can be spent. This whole question is being carefully studied by the committees most directly concerned. I speak of these matters here to ask your help as members of the Institute. If you have ideas regarding the programs of future meetings which you think will help the Institute to meet in the broadest and most satisfactory way the needs of the membership, please give these suggestions to any member of a technical committee or of the technical program committee. I know that these will be helpful to them. It may not be possible to apply all such suggestions but I assure you that they will all be gratefully received and carefully considered."

Following Doctor Osborne's remarks, the first technical sessions of the convention assembled.

Analysis of Registration at Recent Winter Conventions

District	1934	1935	1936	1937
New York City and Foreign (3)	812	694	697	629
North Eastern (1)	179	194	219	222
Middle Eastern (2)	161	153	222	216
Great Lakes (5)	40	38	43	38
Southern (4)	5	6	15	21
Canada (10)	16	21	11	17
South West (7)	11	5	11	12
Pacific (8)	1	1	4	7
North Central (6)	2	1	6	2
North Western (9)	0	1	3	1
Totals	1,227	1,114	1,231	1,165

Technical Sessions

With the exception of the sessions on electric welding and tensor analysis, reports of the technical sessions are not given here since all papers presented have been published in Electrical Engineering, and since all written discussions approved by the technical program committee will appear in subsequent issues. At the session of welding, only one previously published paper was presented, the remainder of the program including a demonstration lecture and a special address. The tensor sessions, included several informal discussions by invited nonmember guests. Brief reports of these 2 sessions are given on succeeding pages.

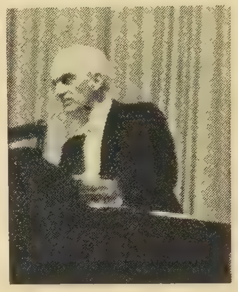
Attendance at the technical sessions, as reported by the technical program committee, is given in an accompanying tabulation. The count in each case was an instantaneous one taken about $1^1/_2$ hours after the session began. The total attendance at any one of the sessions may have been somewhat greater, if those who stayed for only a brief interval were included.

Technical Conferences

As mentioned by Doctor Osborne in his remarks at the opening session of the convention, 4 technical conferences were held on the following subjects: education; network analysis and synthesis; sound; and performance standards and test codes for rotating machinery. All these conferences were featured by interesting informal discussions. At some of them official actions were taken by the sponsoring committees. Brief reports of these conferences are given on succeeding pages.

Address "Power and People"

Following the Edison Medal presentation ceremonies, which took place at a special session of the convention on Wednesday evening, January 27 (reported in succeeding pages), an address entitled "Power and People" was delivered by John C. Parker, vice-president, Consolidated Edison Company of New York, Inc., to those assembled for that occasion. Doctor Parker pictured the place of power, particularly electric power, in the lives of people. Speaking of the work of engineers, who provide the mechanisms necessary for the furnishing of power in usable forms, he said: "The engineer does not live a life of isolation, but on the contrary works with and through other men. His work, . . . involves understanding of, and adjustment to and co-operation with other men . . . His work is definitely more social than that of the physician or of the lawyer or of the minister of souls or of the exponent of the creative arts, each of whom, in a large degree, works as an individual. In that very fact, however, the engineer has at once a satisfaction and a limitation of his social contacts. With



Doctor Parker speaking on "Power and People"

Attendance at Technical Sessions and Conferences

Time		Attendance
Monday		
2:00 p.m.	Opening of convention	250
Technical Sessions		
2:30 p.m.	Communication	200
2:30 p.m.	Selected subjects	100
Tuesday		
10:00 a.m.	Power transmission	250
10:00 a.m.	Tensor analysis	125
2:00 p.m.	Tensor analysis	115
2:00 p.m.	Power distribution	125
Wednesday		
10:00 a.m.	Induction machinery	50
10:00 a.m.	Protective devices	350
2:00 p.m.	Synchronous machinery	70
2:00 p.m.	Electronics	100
Thursday		
10:00 a.m.	Electrical machinery	85
10:00 a.m.	Electrophysics	125
2:00 p.m.	Instruments and measurements	100
2:00 p.m.	Electric welding	110
Technical conferences		
Wednesday		
10:00 a.m.	Committee on education	50
2:00 p.m.	Network analysis and synthesis	75
2:00 p.m.	Noise conference	20
Thursday		
2:00 p.m.	The performance standards, synchronous machinery, induction machinery, and d-c machinery test codes	18
Total registered convention attendance		1,165

er men, largely of identical or at least of ely related interests and limitations, he ls satisfaction for his desires for human tact and such satisfaction easily enough preoccupies his time that he can easily of social understanding of the people om his profession serves or of the social ificances of his own work. . . ."

In consequence of engineering remote- s, we perhaps become obsessed with the nical beauties and interests of our work l with the nan problem co-ordination h our fellows creation and s some per- ctive of how works touch the larger in- ests of soci- . . . ."

Concerning public's in- est in power, ctor Parker l in part: here is a eral public erest in the oblems of ver produc- n and distri- ion that is y out of proportion to any significance t even so important an art has in the irs of men. This would be puzzling if were only a recent phenomenon. It is the less disturbing because of the fact t it has been developed over a period of rs by an ill-considered but perfectly est enthusiasm which has mistaken si- ltaneity of occurrence for a relation of se and effect."

E. R. Thomas, chairman of the inspection trips committee

Speaking of power in industry, he said: merican industry did not set out with the a of trying to apply power to industrial duction and thereafter discover the ans for utilizing power. . . . The power industry saw a commercial opportunity and observed a social responsibility. . . ." Later, he compared the importance of power in industry with that of design for production, modern materials, machine tools, use of tolerance limits, interchangeability of parts, standardization, the use of limit gauges. "All of these elements put together," he said, "might have accomplished nothing had it not been for the superb achievements of distribution which have brought the end results of industry to the final user.

"Note well that every one of these elements. . . has been essential to modern industrial life as we know it; even more than that, has been essential to modern nonindustrial living. Our enthusiasm for one of these elements in which we may happen to be particularly interested—let us say, power—should not run away with our sense of proportion. On the contrary, it seems to me that our pride in our own service becomes greater if we have an adequate picture of where it fits in as an essential and considerable element of something enormously bigger than itself."

Regarding the place of electricity in home and farm life, Doctor Parker said in part: "We need not be at all deprecatory of the importance of our power developments as service to the home or to the farm merely because we may be realistic in our apprehension of the fact that many other things enter into life and that the life is more than meat and the body more than raiment. It is understandable, though not by virtue of that at all defensible, that the specialist should develop an unrestrained enthusiasm for his particular field of human endeavor and that his extreme loyalty might communicate his zeal to others. What is not perhaps quite so clear is that economic, social, and political injuries may result from these widespread and exaggerated enthusiasms. Not alone as a matter of humane consideration, but in self defense against the reactions of disappointed hope, we must be at pains not to arouse desires that we cannot gratify or which, gratified, will be found not all that the body or the soul of man craves."

"Important as is power as an adjunct to factory, farm and home," he concluded, "it, in and of itself, will not revolutionize life. We are, in our most profound relations, biologic creatures and all the conscious mechanical and technical efforts in the world are small factors in determining the essential well-being of our lives. To the extent that we have made our lives in their superficial details depart from our biologic origins, we find the mechanisms of living important. They will be the more important if our perspective keeps them in the proper relation to the other elements of living and to life itself."

Full text of Doctor Parker's address appears on pages 305–11 of this issue.

Attendance at Special Features of Recent Winter Conventions

ture	1935	1936	1937
al registration	1,114	1,231	1,165
oker	550	1,025	1,175
ner dance	442	486	500*
pection trips	815	1,753	926

stimated.

Future AIEE Meetings

North Eastern District Meeting
Buffalo, N. Y., May 5–7, 1937

Summer Convention
Milwaukee, Wis., June 21–25, 1937

Pacific Coast Convention
Spokane, Wash., Aug. 30–Sept. 3, 1937

Middle Eastern District Meeting
Akron, Ohio, Fall 1937

Inspection Trips

As in previous years, the last day of the convention was reserved entirely for inspection trips. Trips were held also on other days of the convention. As a special attraction, a post-convention trip to Bermuda was offered at special rates. About 28 people took advantage of this opportunity to enjoy a mid-winter trip to this popular resort. With the exception of the trip to inspect the mercury turbine of the Public Service Electric and Gas Company at Kearny, N. J., all trips were held as scheduled. Registration for the various trips is indicated in an accompanying tabulation.

The excellent variety of trips, together with the orderliness with which arrangements were made and carried out, elicited many favorable comments. The success of this part of the convention program reflected the efforts of the hard-working chairman of the committee, E. R. Thomas, and of his colleagues: H. C. Anderson, H. M. Case, P. T. Coffin, G. E. Dean, Henry Kurz, W. J. Quinn, H. O. Siegmund, H. B. Stoddard, R. H. Twiss, and W. Y. Vedder.

Smoker

The success of this year's smoker can be judged best by the attendance, 1,175, which is believed to be a record for winter convention smokers. The affair was held in the Grand Ballroom of the Hotel Commodore. An excellent dinner was served, followed by a stage show featuring a pleasing variety of entertainment by well-known radio and motion-picture stars. Ray Perkins, well known for his work on the radio, was master of ceremonies.

E. S. Banghart was chairman of the smoker committee; he was assisted by W. H. Farlinger, H. E. Farrer, P. G. Fredericks, W. H. Harden, W. Jordan, J. E. McCormack, E. J. D. Paterson, R. E. Powers, T. D. Reimers, T. O. Rudd, H. C. Schlaikje, D. W. Taylor, and E. F. Thrall.

Registration for Inspection Trips

Trip	Registration
Anaconda Wire & Cable Company, Hastings-on-Hudson mill	107
General Electric Company sponsored broadcast, "Hour of Charm," NBC studios	95
Warner Bros. moving picture studios	77
S.S. "Monarch of Bermuda"	66
New York Stock Exchange	65
The Associated Press	60
Brooklyn Navy Yard	59
Columbia Presbyterian Medical Center, Sloan radio frequency X-ray generator	56
Westinghouse Lamp Works, Bloomfield, N. J.	52
RCA Manufacturing Company, Inc., Harrison, N. J.	51
National Broadcasting Company studios	45
Independent Subway System, power control board and cable testing equipment	41
Weston Electrical Instrument Corporation	39
New York Museum of Science and Industry, hall of motion	34
Mackay Radio & Telegraph Company, ultra high frequency transmitter	26
The M. W. Kellogg Co., Jersey City, N. J., electric welding	21
S. H. Kress & Company, special lighting and air conditioning installation	17
Edison Wonder House, Brooklyn, N. Y.	15
Public Service Electric & Gas Company, Kearny generating station, mercury turbine	(Cancelled)
Total	926

Dinner-Dance-Buffet Supper

As usual, the dinner-dance proved to be the social high light of the convention. It was held at the Hotel Astor, and was followed by a buffet supper, a feature that has become popular in recent years. A total of

335 attended the dinner-dance, and 250 the dance-buffet supper; some of these attended both, but it is estimated that about 500 were present at the combined affair. Those serving on the dinner-dance committee were: C. M. Gilt, *chairman;* F. L. Aime, T. S. Bacon, L. W. Codding, H. E. Farrer, L. P. Ferris, J. E. Goodale, S. B. Graham, Thomas Maxwell, J. A. McHugh, J. H. Pilkington, and Tomlinson Fort.

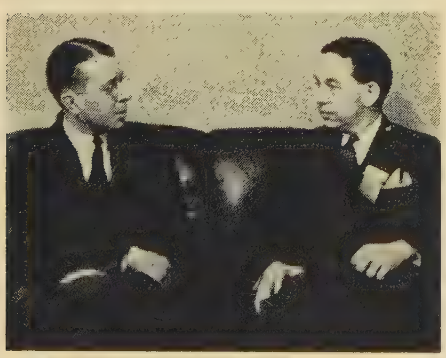
Women's Activities

A program of special entertainment was arranged for the women attending the convention. On Tuesday a group of about 50 visited the Van Gogh Exhibition at the Museum of Modern Art, after which the group inspected the Pedach Exhibition of Decorating Arts and Crafts, at Radio City. This was followed by tea at 4:00 p.m. in the British Empire Exhibition Room at Radio City, after which the group visited the Museum of Science and Industry. After dinner, there was a back-stage tour of the Radio City Music Hall, followed by attendance at the show in that theater. The most popular single event on the women's program was the luncheon and bridge held at the Engineering Woman's Club on Wednesday afternoon.

In addition to the foregoing, some of the women attended some of the regularly scheduled inspection trips, particularly those to the New York Stock Exchange and to the Steamship "Monarch of Bermuda." Serving on the women's committee were: Mrs. George Sutherland, *chairman;* Mrs. E. S. Banghart, Mrs. C. R. Beardsley, Mrs. O. B. Blackwell, Mrs. H. C. Dean, Mrs. Tomlinson Fort, Mrs. C. M. Gilt, Mrs. H. H. Henline, Mrs. A. H. Kehoe, Mrs. E. B. Meyer, Mrs. A. G. Oehler, Mrs. G. S. Rose, and Mrs. H. R. Woodrow.

Directors and Committees Meet

The Institute's board of directors met during the convention, as is the usual custom. A meeting of the national nominating committee also was held, at which nominees for election to Institute officers for the year 1937–38 were selected. Reports of both these meetings appear in succeeding pages.



C. M. Gilt (left) chairman of the dinner-dance committee, and E. S. Banghart, chairman of the smoker committee, comparing notes

Many of the Institute's committees also met during the convention; these were as follows: technical program; research; power generation; production and application of light; standards; electrochemistry and electrometallurgy; automatic stations; Sections; electronics; electrophysics; membership; Group III of the subcommittee on conductors, towers, and wood poles of the power transmission and distribution committee; transformer subcommittee of the electrical machinery committee; and the protective devices committee and its subcommittees on (1) lightning arresters, (2) relays, (3) circuit breakers, switches, and fuses, and (4) fault-current-limiting devices. A scheduled meeting of the committee on electric welding was not held. A luncheon meeting of Student Branch counselors was held, and the newly appointed special committee on broadening of Institute activities also met. Reports of most of these meetings are presented in succeeding pages.

Much credit is due the general committee for the success of the 1937 winter convention. C. R. Beardsley was chairman of this committee; other members were: T. F. Barton, O. B. Blackwell, H. E. Farrer, E. E. Dorting, A. G. Oehler, C. S. Purnell, S. A. Smith, Jr., George Sutherland, and F. P. West.

AIEE Directors Meet During the Winter Convention

THE regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute Headquarters, New York, at 2:00 p.m., on Tuesday, January 26, 1937, adjourning at 5:35 p.m. until 2:00 o'clock the following afternoon, January 27.

There were present: *President*—A. M. MacCutcheon, Cleveland, Ohio. *Past-President*—J. B. Whitehead, Baltimore, Md. *Vice-Presidents*—O. B. Blackwell, New York, N. Y.; C. V. Christie, Montreal, Que.; R. H. Fair, Omaha, Neb.; C. F. Harding, Lafayette, Ind.; W. H. Harrison, Philadelphia, Pa.; N. B. Hinson, Los Angeles, Calif.; A. C. Stevens, Schenectady, N. Y. *Directors*—F. M. Farmer, New York, N. Y.; N. E. Funk, Philadelphia, Pa.; H. B. Gear, Chicago, Ill.; F. E. Johnson, Columbia, Mo.; C. R. Jones, New York, N. Y.; P. B. Juhnke, Chicago, Ill.; W. B. Kouwenhoven, Baltimore, Md.; Everett S. Lee, Schenectady, N. Y.; K. B. McEachron, Pittsfield, Mass.; L. W. W. Morrow, Corning, N. Y.; C. A. Powel, East Pittsburgh, Pa.; R. W. Sorensen, Pasadena, Calif. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y.

Minutes of the board of directors meeting of October 20, 1936, were approved. The minutes of the executive committee meeting held on December 10, 1936, were approved with an amendment changing the name of the special committee on broadening of Institute activities, which was appointed by the executive committee, to "special committee on Institute activities," this committee to prepare for a discussion at the 1937 summer convention of the subject of desirable topics for presentation at Institute meetings and for publication, and to be discharged upon presentation to the board of directors of its report on this session.

Actions of the executive committee under date of November 2, 1936, on applications were reported and approved, as follows: 3 applicants transferred to the grade of Fellow; 1 applicant elected to the grade of Fellow; 19 applicants transferred and 13 elected to the grade of Member; 69 applicants elected to the grade of Associate; 905 Students enrolled.

A report of a meeting of the board of examiners held on January 20, 1937, was presented and approved. Upon the recommendation of the board of examiners, the following actions were taken: 1 applicant was elected to the grade of Fellow; 31 applicants were elected and 5 were transferred to the grade of Member; 97 applicants were elected to the grade of Associate; 204 Students were enrolled. The finance committee reported monthly disbursements as follows: December, $17,647.61; January, $25,368.21; report approved.

The final report of the special committee to consider Associate dues and related matters was submitted, with the recommendation that the present constitution and bylaws be unchanged. The board voted that the committee's report be accepted and published in Electrical Engineering, and that the committee be discharged. (The report appears elsewhere in this issue.)

Upon the recommendation of the committee on co-ordination of Institute activites, the following schedule of meetings in 1938 was adopted: winter convention, New York, N. Y., January 24–28; North Eastern District meeting, Pittsfield, Mass., in the spring; summer convention, Washington, D. C., June 20–24; Pacific Coast convention, Portland, Ore., dates to be determined later.

Approval was given to the dates of August 30 or 31 to September 3 for the 1937 Pacific Coast convention, already scheduled to be held in Spokane, Wash.

Upon the recommendation of the committee on student Branches, the board authorized the organization of student Branches of the Institute at Columbia University, New York, N. Y., Northwestern University at Evanston, Ill., and Tulane University, New Orleans, La.

The president was empowered to appoint 2 representatives of the Institute upon the council of the American Association for the Advancement of Science for the year 1937.

G. G. Post was appointed a representative of the Institute upon the Commission of Washington Award for the unexpired term ending August 1, 1938, of William B. Jackson, deceased.

The committee on award of Institute prizes reported its recommendations on various suggestions for modifications in the rules for the award of Institute prizes. The board voted its approval of the recommendations, which involved the following changes in the rules and the reprinting o

e pamphlet containing the rules:

Provision that the national prize for branch pers will be based upon the student year July 1 June 30, inclusive, rather than the calendar r as at present. This is in accordance with the ommendation of the conference of officers, egates, and members held in Pasadena, Calif., June 1936. It is recommended that this change brought about by the adoption of the following cific changes in the present rules.

ge 3, paragraph at the bottom of the page beging "Only papers presented. . . ., etc."—Modify read as follows:

or the national best paper prize and the national ze for initial paper, only papers presented during calendar year shall be considered except those the best paper prize in the class of public ations and education. In this class all papers sented subsequent to those considered at the e of the last previous award in this field and or to the end of the last calendar year will eive consideration. For the national prize for nch papers only papers presented during the ceding academic (college) year shall be conered.

ll papers approved by the technical program nmittee . . ., etc."

ge 6, paragraph 6—Modify to read as follows: nly papers presented during the calendar year ll be considered for the prize for best paper l for initial paper. Only papers presented ing the preceding academic (college) year shall considered as eligible for the Branch paper prize. ey must be submitted in duplicate by authors, by officers, of the Section, Branch, or District cerned to the District secretary on or before following dates: best paper and initial paper, ruary 15; Branch paper, July 15."

this recommendation is adopted, it is understood t the committee on award of Institute prizes l this year consider for the national Branch per prize only papers presented between Janu- 1 and July 1, 1936.

]Provide for a District prize for a graduate dent paper. This is in accordance with a preus recommendation of the prize award commit-, approved by the board of directors on May 25, 36, but not heretofore incorporated in the rules national and district prizes.

the top of page 6, add item 4, prize for graduate dent paper.

The District prize for graduate paper may be arded for the best paper based upon graduate rk and presented at a national, District, Section, Branch meeting of the Institute. At the time presentation, the author must be a graduate dent and either a member or an enrolled Student the Institute. In the case of co-authors, the duate requirement applies to all and the memship requirement applies to at least one of the uthors."

ge 6, paragraph 6—Modify the revision set th under item 1 above to read as follows:

nly papers presented during the calendar year ll be considered for the prize for best paper l for initial paper. Only papers presented ing the preceding academic (college) year shall considered for the prize for Branch paper and graduate student paper. They must be subted in duplicate by authors, or by officers of the tion, Branch, or District concerned to the strict secretary on or before the following dates: t paper and initial paper, February 15; Branch per and graduate student paper, July 15."

A report of the Institute policy commite on recommendations of the committee safety codes for an expansion of that nmittee's scope was presented and apoved. The report included the statent: "It is the feeling of this committee at there are many types of activity look- to increased safety, which lie beyond e normal purposes of the AIEE. It is t that any expansion of the Institute's rk on safety should be limited strictly to e technical and engineering aspects of ety, and particularly should not conflict h the safety work of any other organizan." It recommended that "the chairn of the committee on safety codes be ormed that the board of directors is inested in the possibility that the Institute, within its proper scope, may make further contributions to the cause of safety than it is now doing, and will welcome any specific suggestions to this end from the committee on safety codes."

The publication committee reported that it is making a thorough study of publication policy, and certain recommendations, including increases in the budget for ELECTRICAL ENGINEERING for the present year, were approved. The committee may submit additional recommendations after further consideration and discussion of the matter at the conference of officers, delegates, and members during the summer convention.

President MacCutcheon presented abstracts of reports which he had received, upon his request, from the technical committees and several of the general committees. The board referred these reports to the chairman of the committee on co-ordination of Institute activities for a survey of committee activities and any recommendation he may have for the Board.

The final report of the special committee to revise Section territories was presented. The board voted that the committee's report be accepted, that the actions recommended be adopted, the changes to become effective August 1, 1937, and that the committee be discharged with the thanks of the board.

Reference was made to the publication in the December 1936 issue of ELECTRICAL ENGINEERING of a report of the committee on professional recognition of Engineers' Council for Professional Development, which had not yet been approved by ECPD, and comments on which were invited. This report was referred to the committee on economic status of the engineer, with the understanding that a notice would be published in ELECTRICAL ENGINEERING that the report had been referred to this committee, the chairman of which has requested that Institute members send to him their comments on the subject. (This notice appears elsewhere in this issue.)

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Nominating Committee Announces Candidates

A complete official ticket of candidates for the Institute offices that will become vacant August 1, 1937, was selected by the national nominating committee at its meeting held at Institute headquarters, New York, N. Y., January 26, 1937. This committee, in accordance with the constitution and bylaws, consists of 15 members, one selected by the executive committee of each of the 10 Geographical Districts, and 5 selected by the board of directors from its own membership.

The following members of the committee were present: A. W. Berresford, New York, N. Y.; O. B. Blackwell, New York, N. Y.; C. V. Christie, Montreal, Canada; N. E. Funk, Philadelphia, Pa.; E. E. George, Chattanooga, Tenn.; K. L. Hansen, Milwaukee, Wis.; R. E. Kistler, Seattle, Wash.; H. S. Lane, San Francisco, Calif.; T. H. Morgan, Worcester, Mass.; J. W. Ramsay, Austin, Tex.; R. W. Sorensen, Pasadena, Calif.; A. C. Stevens, Schenectady, N. Y.; A. L. Turner, Omaha, Neb.; J. B. Whitehead, Baltimore, Md., and W. E. Wickenden, Cleveland, Ohio; also H. H. Henline, New York, N. Y., secretary of the committee.

The following is a list of the official candidates selected by the committee:

FOR PRESIDENT

W. H. Harrison, assistant vice-president, department of operation and engineering, American Telephone and Telegraph Company, New York, N. Y.

FOR VICE-PRESIDENTS

I. Melville Stein (Middle Eastern District, number 2) director of research, Leeds & Northrup Company, Philadelphia, Pa.

Edwin D. Wood (Southern District, number 4) general superintendent, Louisville Gas & Electric Company, Louisville, Ky.

L. N. McClellan (North Central District, number 6) chief electrical engineer, U.S. Bureau of Reclamation, Denver, Colo.

J. P. Jollyman (Pacific District, number 8) hydroelectric and transmission engineer, Pacific Gas & Electric Company, San Francisco, Calif.

M. J. McHenry (Canada District, number 10) manager, Toronto district, Canadian General Electric Company, Ltd., Toronto, Ont.

FOR DIRECTORS

C. R. Beardsley, superintendent of distribution, Brooklyn Edison Company, Inc., Brooklyn, N. Y.

V. Bush, vice-president and dean of engineering, Massachusetts Institute of Technology, Cambridge, Mass.

F. H. Lane, manager, engineering division, Public Utility Engineering & Service Corporation, Chicago, Ill.

FOR NATIONAL TREASURER

W. I. Slichter, professor of electrical engineering, Columbia University, New York, N. Y.

The constitution and by-laws of the Institute provide that the nominations made by the national nominating committee shall be published in the March issue of ELECTRICAL ENGINEERING. Provision is made for independent nominations as indicated in the following excerpts from the constitution and by-laws:

CONSTITUTION

Sec. 31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the National Secretary when and as provided in the By-Laws; such petitions for the nomination of Vice-Presidents shall be signed only by members within the District concerned.

BY-LAWS

Sec. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (Constitution), must be received by the secretary of the National Nominating Committee not later than March twenty-fifth of each year, to be placed before that committee for inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the National Nominating Committee in accordance with Article VI of the Constitution and sent by the National Secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(Signed) National Nominating Committee
by H. H. Henline, *Secretary*

BIOGRAPHIES OF NOMINEES

In order that those not personally acquainted with the nominees may know something of them and their qualifications for the Institute offices for which they have been nominated, brief biographical sketches are given in the "Personals" columns of this issue.

Some Personalities a

(1) J. E. Clem (left) of Schenectady, N. Y., member of committee on electrical machinery and author of a convention paper, and K. K. Paluev of Pittsfield, Mass., member of committee on research

(2) Director N. E. Funk of Philadelphia, Pa., studying the convention program

(3) Past Vice-President (1928–30) B. D. Hull of St. Louis, Mo. (formerly of Dallas, Texas)

(4) J. W. Ramsay, of Austin, Texas, representative of the Institute's South West District on the national nominating committee

(5) D. C. Prince of Philadelphia, member of Lamme Medal and protective devices committees

(6) Director H. B. Gear (left) of Chicago, Ill., and G. A. Kositzky of Cleveland, Ohio, chairman of the national membership committee

(7) G. W. Penney (left) of East Pittsburgh, Pa., author of a convention paper, conversing with R. C. Mason, also of East Pittsburgh, chairman of the committee on electrophysics

(8) H. R. Beardsley of Brooklyn, N. Y., chairman of the winter convention committee and nominee for director

(9) Past Vice-President (1930–32) I. E. Moultrop of Belmont, Mass., conversing with W. F. Dawson of Holliston, Mass., after the Edison Medal ceremonies. Mr. Dawson was chairman of the Lynn (Mass.) Section 1927–8

(10) Director C. A. Powel (right) of East Pittsburgh, Pa., working on a bit of discussion. F. E. Terman of Stanford University, Calif., member of committees on education and communication, looks on, perhaps assisting

(11) Director and Past Vice-President R. W. Sorensen of Pasadena, Calif., selling the idea of San Francisco for the 1939 summer convention

(12) Waiting for the next event. Left to right: A. C. Seletzky, counselor of the Student Branch at Case School of Applied Science, Cleveland, Ohio; W. C. Kalb, secretary of the Cleveland Section; P. H. Daggett of New Brunswick, N. J.; and J. W. Barker of New York, N. Y., member of several Institute committees

(13) A. P-T. Sah of the National Tsing Hua University, Peiping, China, author of 2 convention papers, explaining dyadics to 2 past-chairmen of the Rochester (N. Y.) Section: F. C. Young (center), chairman 1931–32, and W. M. Young, chairman 1934–35

(14) Editor G. Ross Henninger (left) disc tensor analysis with Gabriel Kron of Schene N. Y., author of numerous treatises on that su

(15) K. L. Hansen, past-chairman of the M kee (Wis.) Section, was busy stirring up interest Institute's forthcoming summer convention home town. He is chairman of the 1937 su convention committee

(16) W. E. Wickenden (left) chairman c Cleveland Section and representative of the M Eastern District on the national nominating mittee, discussing a point of mutual interes National Treasurer W. I. Slichter, of New Yo

(17) Past Vice-President W. H. Timbie (l Cambridge, Mass., greeting President A MacCutcheon of Cleveland, Ohio, upo arrival at the convention

(18) P. L. Alger of Schenectady, N. Y., man of the subcommittee on sound, stud preparing for the technical sessions

(19) Vice-President C. Francis Hardin Lafayette, Ind., another busy member of the summer convention committee

e Winter Convention

. W. Rogers of Schenectady, N. Y., chair- the committee on general power applica- njoying a good joke

rs. C. S. Weist is an interested observer as J. H. Payne, both of Washington, D. C., apped" at the dinner-dance. Mr. Payne was appointed chief of the electrical , Bureau of Foreign and Domestic Com- United States Department of Commerce

st Vice-President (1930–32) H. V. Car- of Pullman, Wash., chairman of the com- on code of principles of professional

rector W. B. Kouwenhoven (right) of re, Md., discussing a question with J. C. gh of Cambridge, Mass., a member of the tee on protective devices

rector C. R. Jones, of New York, at the dance. He was chairman of the New York 1933–34

. E. Crawford of Milwaukee, Wis., member committee on electric welding and treasurer 1937 summer convention committee

(7) A busy period at the inspection trips desk; on duty (left to right): H. B. Stoddard, member of the inspection trips committee; L. A. Pagano; and Miss L. Lawrie of the headquarters staff

(8) Vice-President O. B. Blackwell (left) and Mr. and Mrs. A. F. Dixon, all of New York, at the dinner-dance

(9) T. A. Worcester of Schenectady, N. Y., member of the committees on power transmission and distribution, and technical program, paying close attention to a weighty discussion

(10) J. A. C. Warner, general manager of the Society of Automotive Engineers, apparently has Mrs. H. H. Henline interested in the engineering features of some of the 1937 models

(11) Col. Azel Ames (left) of New York, telling Mrs. George Humphrey of Hagerstown, Md., a good story, while H. W. Osgood, chairman of the Washington (D. C.) Section interests Mrs. T. O. Rudd of New York (right)

(12) Director F. M. Farmer, of New York, chairman of the headquarters committee, emphasizes an important point to Mrs. A. E. Silver, of New York

(13) National Secretary H. H. Henline having a serious discussion at the dinner-dance with Mrs. John Arms of New York

(14) T. R. Tate, secretary of the Washington (D. C.) Section, and F. M. Feiker, executive secretary of American Engineering Council, Washington, apparently exultant over the fact that the board of directors voted to hold the Institute's "1938" summer convention in that city

(15) Mrs. W. K. Vanderpoel of New York, listens to I. M. Stein of Philadelphia, chairman of the publication committee and nominee for vice-president

(16) Past Vice-President (1927–29) J. L. Beaver (left) of Bethlehem, Pa., and A. G. Oehler, chairman of the New York Section, discussing important matters at the dinner-dance

(17) Vice-President W. H. Harrison (left) of New York, nominee for president, getting a few pointers from the fifteenth president (1902–03) of the Institute, Chas. F. Scott, of New Haven, Conn.

(18) Mrs. I. M. Stein of Philadelphia, appears somewhat spellbound by the story she is hearing from Past-Manager (1923–27) W. K. Vanderpoel, of New York

(19) J. P. McKearin of Springfield, Mass., chairman of the committee on protective devices

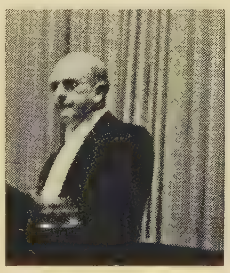
Edison Medal for 1936 Presented to Alex Dow

FOR "outstanding leadership in the development of the central station industry and its service to the public," the 1936 Edison Medal, highest award of the AIEE, was presented to Doctor Alex Dow, president, Detroit (Mich.) Edison Company, at a special session of the Institute's 1937 winter convention, on the evening of January 27. Doctor Dow has been a member of the Institute for 44 years, having been elected an Associate in 1893, and transferred to the grade of Fellow in 1913. He has been president of the Detroit Edison Company since 1913.

A. M. MacCutcheon, president of the Institute, presided over the ceremonies, introducing first H. P. Charlesworth, past-president of the Institute, and chairman of the Edison Medal committee, who briefly outlined the history of the medal and the terms of its presentation. Mr. Charlesworth's remarks follow:

Past-President Charlesworth Outlines History of Medal

"The Edison Medal was founded by an organization of associates and friends of Thomas A. Edison who desired to commemorate the achievements of a quarter of a century in the art of electric lighting with which Edison had been so prominently identified.



Past-President Charlesworth outlining history of medal

"It was decided that the most effective means of accomplishing this object was by the establishment of a gold medal which could serve 'as an honorable incentive to scientists, engineers, and artisans to maintain by their works the high standard of accomplishment' which had been set by Edison. The American Institute of Electrical Engineers was invited to undertake the responsibility of making the awards. The Institute accepted and organized the Edison Medal committee, or board of award, composed of 24 members.

"Three of these members are appointed each year by the president of the Institute to serve for a term of 5 years each; 3 are elected each year by the board of directors from its own membership to serve for a term of 2 years each; the other 3 members are *ex-officio*, the president, the national treasurer, and the national secretary of the Institute.

"The by-laws of the committee provide for making one award each year, and the deed of gift specifies that the award shall be made to some one resident in the United States or Canada, for meritorious achievement in electrical science, electrical engineering, or the electrical arts.

"The medal was designed by James Earle Fraser, and carries on the obverse the portrait of Thomas A. Edison, and on the reverse an allegorical conception of the genius of electricity crowned by fame."

Louis H. Egan Eulogizes Doctor Dow

Following Mr. Charlesworth's remarks, President MacCutcheon introduced Louis H. Egan (A'08, M'15) president, Union Electric Light and Power Company, St. Louis, Mo., a long-time friend, close associate, and great admirer of Doctor Dow. Mr. Egan outlined some of Doctor Dow's accomplishments as president of the Detroit Edison Company, and related many interesting anecdotes demonstrating his fine personal characteristics.

Going back 35 years, Mr. Egan told of his first meeting with the medalist, on which occasion he (Mr. Egan) was seeking employment (which he obtained). Speaking of these early associations, he said in part: "Mr. Dow was beyond belief in his method of treatment and in the rare privilege that came to be mine of being welcomed into their home. There I came to understand one of the reasons for his success, and she is here tonight; I would indeed be derelict if I didn't mention and give full credit to the very delightful and lovely hospitality that she offered to me at that time—Mrs. Dow."

"I am not going to undertake," Mr. Egan continued, "to tell you here tonight very much, if anything, about the big boilers, or about the unusual transmission system, and the substations, and the stores department, and how we handled the meters, and all the rest of this, our public relations, and so forth. You will hear those from others, possibly, and if you don't, you can find them out very readily. They have been published many times.

"I should like to tell you just a little of the human side of this gentleman that we are honoring here tonight. I will mention just in passing, if I may, something about this company that he runs, and, rather than going to one of his intimate friends, or refreshing my own recollection on the subject, I should like to take a chapter out of the book of...the Public Utilities Commission of the State of Michigan. It is paraphrased a little, because I think I write it better than they do. It may be briefed in spots, but it is designed to serve its purpose here and the basis of it can be found in the decision of that commission; it says this:

" 'The Detroit Edison Company was organized in 1903 under the laws of the state of New York. At that time Michigan did not have corporation laws suitable to the operations of the Detroit Edison Company, which they proposed to conduct.

" 'At the time of its organization, the Detroit Edison Company took over the Edison Illuminating Company, Detroit and Michigan corporation, which had been organized under the Michigan laws, and also the Peninsula Electric Light Company, a Michigan corporation which had been organized in 1898

" 'The Eastern Michigan Edison Company was incorporated July 24, 1906, under the laws of the state of New York, as a subsidiary of the Detroit Edison Company, for the purpose of doing certain classes of business, most of it privately owned. Electrical properties in the southeastern part of the state have since been consolidated in the Detroit Edison Company. Briefly, it covers practically all of Michigan within 50 or 60 miles of the city of Detroit, and recently it purchased the property, plant, and facilities of the Michigan Electric Power Company, operating in what is known as the thumb of Michigan. The territory served by the company has a population of approximately 2,500,000 people.

" 'The growth of the company since its organization in 1903 has been phenomenal. At the close of that year it had, according to its books, total fixed capital of less than $7,000,000. At the end of 1935, its total fixed capital was something like $296,000,000. Thus we see that in 33 years, beginning with 1903, the total fixed capital of this utility was multiplied by more than 42 times.

" 'In addition to serving electric light and power in the territory above described, the company supplies an extensive steam-heating service, principally in Detroit. The investment which might properly be allocated to the steam-heating business approximates $15,000,000. It also has a small amount of manufactured-gas business.

" 'The Edison Company has grown greatly with the growth of the southeastern part of Michigan. When the company began business in 1903, the population of its territory was only about 300,000. It is now about 8 times that amount. During its existence it has purchased and taken over about 50 electric light and power plants previously owned by municipalities or by small utility companies.

Louis H. Egan sketching high lights in life of medalist

" 'It owns and operates some 7 or 8 rather small water powers on the Huron River; although most of its energy is generated in steam plants located in the vicinity of Detroit, it has one rather large steam plant near its gas utility at Marysville.

" 'The Utlity under consideration has always taken care of the interests of the public. It has been a very important factor in the phenomenal growth of the territory it serves. It was one of the first utilities in the country to begin the electrification of rural territory, and at the present time about 75 per cent of the farms in its territory that it has occupied for a considerable period of time have been electrified.

" 'The stock of the company is widely distributed. It has almost 14,000 stockholders. There is no doubt about the fact that the Detroit Edison Company is one of

outstanding electric utilities in this country. It is not owned by any holding company. It is an independent concern. Ever since its organization it has been most efficiently managed and operated. Its head during its entire history has been Alex Dow, one of the foremost electric light and power men in the United States.'

"I think probably that is the greatest tribute that has ever been paid by a regulating body to the electric light and power industry, to the man who headed a company, in this whole country, since regulation began. It is merited beyond belief. For over 40 years he has been the guiding factor and the principal factor in the creation of this company. It is recognized both in the United States and abroad as a model example of its kind."

Mr. Egan next spoke of Doctor Dow's broad general interests, mentioning specifically several widely divergent subjects with which he is conversant.

Speaking of Doctor Dow's achievements in the electric power industry, Mr. Egan said: "Would you like to know somebody who thought of most of the things that come to your minds about the light and power industry today, thought of them 25 years ago, and forgot them? If you think that you are about to develop something new in this industry, I warn you, because I have made the mistake, you had better go back and dig in the proceedings of the National Electric Light Association, and of the Association of Edison Illuminating Companies, and there you will find them expounded about a quarter of a century ago by Mr. Dow. It doesn't make any difference whether it deals with customer relations, whether it deals with street lighting, whether it deals with the contacts of municipalities, or government control: it is all there. I have looked them up and read them.

"What a great treat it must be to all these thousands and thousands of young men and women, just as it was to me, to come in contact with a mind of that kind in this business! I can't begin to tell you the thankfulness that is in my heart for the things that he did to me, sound, true, sane, stable principles that he has followed and preached since he started.

"You talk about there being no romance in business! Only careless, foolish people say that. A young boy in Scotland—nobody to help him—an orphan in his early years, people to assist; he starts out by just sheer industry, perseverance, the will to make good, he comes to this country, takes half a dozen simple jobs of one kind or another, all the time storing up in this retentive memory of his the things that are going to be to his advantage in the future.

"Finally he lands in Detroit to put in a municipal street lighting system, and, after he did it, the local company said: 'There is the type man we want.'

"He has been there 41 years doing that job. Why, it is an inspiration beyond belief! It is the kind of thing that is the United States of America at its best."

Concerning Doctor Dow's humanitarian activities, Mr. Egan said: "What he has done for people all over this country will never be known." He then mentioned several specific instances in which Doctor Dow had rendered personal assistance to people in need.

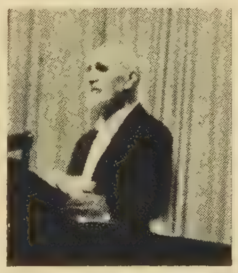
"His breast is shining with unseen medals for the goodness that he has done," Mr. Egan concluded. "I could continue this eulogy for a long, long time It has been said and said well that a big enterprise is a shadow of a man. Perhaps those who don't think well imagine it becomes trite, but it is true; it never was more fully exemplified than it was in this case.

"But the sun is setting, and the shadow becomes long. It isn't a dark shadow. It is a shadow that shines with a roseate light, a white shadow, if you will, the kind of shadow that will last forever in the district where it has first fallen, and that is what his shadow will be on his chosen state and his chosen city."

President MacCutcheon (right) presenting medal and certificate to Doctor Dow

Doctor Dow Responds

Immediately following Mr. Egan's address, President MacCutcheon presented the medal and certificate to Doctor Dow, who responded, in part as follows:



Doctor Dow responding

"I asked Louis Egan to tell you some of my sins and I didn't hear all that he said... but I suspect that he had been hunting up my somewhat negative virtues and reciting those to you.

"...I plead guilty to having contributed to the development of the central station industry. I found myself in that industry, to my own great surprise, dealing with, to begin with and for several years almost continuously, properties that had been failures, trying to put them on their feet, succeeding quite a bit; at other times saying that in this particular case what was wanted was not a diagnosis and medication but a postmortem. These things happened, and that experience, I know, was exceedingly valuable to me in teaching me the things that just could not be done in that industry....

"By the time that I got through listening to the...remarks of Louis...I came to the conclusion that I must have failed in my vocation; instead of being an electric-light man doing the day's work as it came along, the best I knew how, glad when the day was done, I ought to have been a missionary or a member of a settlement, preaching the gospel... I am glad that that destiny... miscarried. I am afraid that I should have been even more weary of it than I have been at times of the day's work as it is.

"...I wish you would think of me as somebody who has just, as I have already said, done the day's work as it came to him, looked ahead, saw what could be foreseen, sometimes having a vision that was almost prophetic... At times it has been given to me to see what was coming and to see the possibilities of meeting the on-coming event in such manner as would conduce to the welfare of the service for which I was responsible; that I have taken that service seriously I wish you would think of as being assured of.

Mrs. Dow after the ceremonies

"As far as investment goes, it is rather a serious matter to be responsible for $300,000,000 of other people's money. As far as the care and welfare of employees go, for groups that have ranged in the last few years, even during the depression period up to about 8,000 people, and as far as service to the public goes, that Mr. Egan has stated to you; and it is a service that is unusual, exceptionally comprehensive, covering and trying to reach, everybody.

"We have been able there to have accepted by our authorities the doctrine of the economic area, separating out from individual municipalities, each insisting upon having its own accounting and its own particular rate schedule...and we have an integrated area there that is willing to be dealt with as a whole. That is the correct theory, we believe. I know that I was one of the first to point out that that was how it should be, that a service such as the central station service is, could not be congeries of local services, but must be a broad service extending over the area which was economically one area; and that is what has been sought by my people and by myself.

"Now...I have by example as well as by precept shown what may be done, shown that it is possible to get along peacefully, shown that it is possible to have no labor trouble (and I speak for myself personally, and I am touching wood when I say that in these troublesome days—touching wood and making a little prayer that it will continue). I began to boss men when I was a 14-year old boy. The men never bothered me because they were all quite willing to be bossed—it saved them from doing any thinking; but the boys of my own age, or a little older, I had to fight it out with every confounded one of them before I could get peace. I don't know any other way to get peace either in business or in politics, but to fight it out when you have to—to avoid it as long as you can but to fight it out when you have to.

"So it has gone, and, to play fair with these divergent interests and interests that may become divergent, has been my job in life—that much more than any choice in engineering matters or any development of new principles or any application of established principles.

"Let me confess here...that I have almost forgotten what it is to be an electri-

cal engineer.... I have to tell them [electrical engineers] when they come and talk to me about something new: 'Now that is all right, but settle down and tell it to me in words of one syllable.' Usually it is possible to do that and I, having no facilities whatever in the language of the mathematician and the symbols in which he expresses an idea concisely and clearly,...am glad to revert to the one-syllable plan.

"...Forty-five or 50 years ago I knew all there was to know about telegraphy, but now I don't even know the language. And it is so with many, many matters of electrical engineering nowadays... Still, I have an understanding mind; still, I am glad to have a new problem brought to me, glad to hear how it has been solved, and glad to settle down and think about it and think how that is going to fit into my day's work, into the problem of serving 600,000 customers scattered over 6,500 square miles, and that is what engineering means to me; but as for being an electrical engineer—no....

"...I found the United States, when I came to them, more than 50 years ago, a place that welcomed the youngster who was willing to take it as he found it, who had no call to show it the error of its ways, and was not only willing to take things as he found, but also willing to work hard at whatever work Providence put before him. I turned my hand to a good many things. I had a certain facility at mechanical employments.

"Before I was 20 years old I came to the United States, and I ultimately landed... into the electric light and power industry, and have stayed with it, grown up with it, was an early operator in that industry and have seen it become what it is. That has taken above all things an understanding of the American people. It has taken an infinite patience. It has taken that foresight with which I thank the Lord He has given me a certain amount of. It has taken the judgment as to what should be done when one felt what was coming. So far I have had good fortune. I hope it will continue. I trust it will continue....

"Still, after all, in these matters for which I have been given much praise tonight, I have tried to understand, I have tried to make it easier for those who needed help, and tried when it was necessary to speak the truth without malice. I have tried to be patient. I have tried even to suffer fools gladly, although that has been perhaps the most trying thing that I have had to do....

"As it is, it is anything but engineering. I wouldn't unless I were an engineer by thought and by a certain amount of training be where I am, but it is anything but engineering in the day's work; it is finance, it is management, it is law, it is politics—which I don't approve of at all. You know, you need a big sense of humor to keep your patience with politics....

"As for taking care of my people, well, and other people—things that have been wished upon me: I never believed in welfare systems—no welfare system that I know of, and that applies to a little bit of an organization...right up to the wonderful scheme for the betterment of 15 or 20 million people that we now have on our lists, so many of them capitalized with 3 or 4 initials...As to these things, I admit having done what came to my hand, and I have summed up my philosophy of such matters in a very, very few words: ...Do what you can, what is within your powers, what is within your duty, if it may so happen, for ...the person—man or woman—who does need help; do it quietly and kindly, without any fuss and botheration. Don't do it mechanically. Do it personally. If you cannot do it personally yourself, at least see that the job is done. Delegate it to someone that is light of hand and will not try to make people feel grateful. That kind of gratitude I don't much like. It reminds me of that definition of gratitude: 'Gratitude is a lively sense of favors to come.' Do it quietly, as I have said; do it patiently and kindly; thank God that you have had the chance to do it; and, forever afterward, keep your mouth shut about it.

"I think I have said a plenty. Thank you for listening, and this [the medal] I am highly honored by."

Reports of 15 Committee Meetings Held During the Winter Convention

Brief reports of the meetings of 16 Institute committees and subcommittees held during the Institute's recent winter convention are presented herewith, as prepared by the committee chairmen or from notes submitted by them. These reports cover meetings of 2 general committees, 6 technical committees, and 7 subcommittees of technical committees. Reports of the meetings of 4 subcommittees of the protective devices committee have been combined with that of the parent committee.

No report of the meeting of the committee on electrophysics was submitted, but according to Chairman R. C. Mason that committee "met to consider plans for future activities." In addition, no report of the standards committee meeting is included here, but actions of this committee on items of interest to the membership are reported in the "Standards" columns elsewhere in this issue. A scheduled meeting of the committee on electric welding was not held.

Membership Committee

By G. A. Kositzky, Chairman

Some 21 of the members of the national membership committee attended the meeting of the committee held January 27, 1937, at national headquarters in New York during the recent winter convention. The several matters of routine business that were discussed have been reported to all members of the committee through the medium of the minutes of the meeting.

Special attention was called to the new pamphlet containing an article by E. S. Lee, former national membership chairman, entitled "Membership in the American Institute of Electrical Engineers." This article is highly informative concerning Institute activities, and has been distributed by mail to all Institute members. These booklets are available from national headquarters.

Sections Committee

By W. H. Timbie, Chairman

The Sections committee is unanimous in believing that a thoroughgoing survey should be undertaken immediately of the activities of the Sections. The majority believes that a "field survey" should be made by a competent investigator; the rest are of the opinion that a questionnaire survey is all that is necessary. Consequently, it is proposed that a special survey be made, the committee sending to the chairman of each Section a "self-analysis blank," by means of which each Section chairman, assisted by his Section secretary, may analyze the activities of his Section stating specifically:

A. Aims or objectives of the Section.

B. Activities now carried on to attain these objectives.

C. Critical examination of the results of these activities.

D. Necessary or desirable change in activities.

The objective of this survey is: first, that the Sections examine themselves in order to crystallize their objectives and reasons for and results of their activities; second, from a study of the returns the Sections committee hopes to obtain facts and data that will enable it to assist the several Sections in reaching a clearer understanding of the aims and in more effective methods of obtaining them.

It is especially desired that ways may be opened up for: (*a*) further co-operation between a Section and other community-minded groups that would profit by the help of the engineer; (*b*) more effective co-operation between the Sections committee and the various Sections; (*c*) greater co-operation between Sections. This preliminary survey should likewise give a fair indication as to whether a "field survey" is necessary or desirable.

The committee plans to co-operate to the fullest extent with the newly appointed special committee on the broadening of Institute activities.

Automatic Stations Committee

By M. E. Reagan, Chairman

Because of the enthusiastic reception that has been accorded the subcommittee's report on supervisory control and telemetering, by operating people, it was decided to bring this report up-to-date and request its publication in Electrical Engineering. The subcommittee appointed to follow this program is as follows: Chester Wallace, American Telephone and Telegraph Company, New York, N. Y.; P. A. Borden, Bristol Company, Waterbury, Conn.; M. E. Reagan, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.; and A. E. Anderson, General Electric Company, Philadelphia, Pa.

It was suggested that the committee undertake a study of operating practice on short-circuiting or open-circuiting of neutral-grounding resistances in case of circuit

eaker failure on ground faults. It was ieved, however, that this was a function the committee on power transmission and tribution. It was decided to offer the istance of the automatic stations comttee to the committee on power transssion and distribution in co-ordinating y investigation of this problem.

A request for a round-table discussion on tomatically controlled hydroelectric generng stations at the Institute's 1937 summer nvention was discussed at some length. was decided that the committee would onsor such a meeting if the convention nmittee considers that there is enough neral interest in the subject. At the quest of the summer convention comttee, the automatic stations committee l co-operate in a general discussion on ontrol" to be held at that convention.

Preliminary reports were made by 2 subnmittees on the general subjects of:

Battery-charging methods in unattended stans.

Reclosing of breakers on bus-differential operan.

AIEE Standards No. 26, which is now dergoing consideration by the American ındards Association, was again reviewed.

ommittee on Electrochemistry and Electrometallurgy

By F. O. Schnure, Chairman

On the subject of electrolytics, the comttee is now formulating plans for a roundle conference to be held in connection h the Institute's forthcoming summer nvention. It is the committee's plans to oaden the scope of the intended discusn by inviting to participate in it, mems of other technical societies interested the various aspects of the general subject electrolytics. As chairman of the comttee to plan this conference, N. R. Stansel of the industrial engineering department, General Electric Company, Schenectady, N. Y., and former chairman of the committee on electrochemistry and electrometallurgy, was appointed. Looking forward to the 1938 winter convention, the committee also is considering the possibility of developing for the program of that convention a symposium on the subject of electrolytics, or some other subject growing out of the intended summer-convention round-table conference.

There was considerable discussion on the question of a "definition of the committee's function." As this is now "defined" or understood, the scope of the committee's activities can include either the thermal applications of electricity, the electrolytic applications of electricity, or both. To study the subject and report later to the committee a recommended definition of function and scope of activity, a subcommittee has been appointed.

Brought forth during the committee's general discussion were strong suggestions to the effect that the Institute membership should be "classified according to interests and professional work."

Committee on Protective Devices

By J. P. McKearin, Chairman

Rules were adopted to govern the standing subcommittees of this committee in the preparation of their annual reports. These reports are to show the extent of the subcommittee programs and to give all members of the protective devices committee and all members of all the subcommittees the benefit of a record of the work that has been done, so as to maintain the continuity of subcommittee work from year to year.

A resolution was adopted, recommending to the Institute's standards committee that the revised AIEE Standards No. 22, on "air switches," be published in report form.

Arrangements were made to obtain improvements in the report on Standard No. 23, for "relays," to bring these Standards up to date.

Plans were made for participation by this committee with the committees on power transmission and distribution and electrical machinery in a proposed joint session at the Institute's 1937 summer convention on "lightning protective equipment and insulation co-ordination." Considerable interest has been shown in this type of session.

Circuit Breakers, Switches, and Fuses

The subcommittee on circuit breakers, switches, and fuses, H. J. Lingal, chairman, made further plans for its work on recommendation for improvements in AIEE Standards No. 19, for "oil circuit breakers," and proposed Standards No. 25, for "fuses above 600 volts." This work is the result of suggestions received from the industry at large in response to the invitation for opinions, criticisms, and suggestions printed on the recently published reports on these 2 standards.

Relays

The subcommittee on relays, E. E. George, chairman, reviewed its program, which includes: "application of electronics to relay protection," "trend of distribution relay protection," "standardization and simplification of relay design and application," and "high-speed protection and reclosing."

Fault-Current-Limiting Devices

The subcommittee on fault-current-limiting devices, J. O'R. Coleman, chairman, reviewed its program and made further plans for its work which includes "a survey of grounding practices," "mutually-coupled reactors," and preparation of new standards for "fault current limiting devices for neutral grounding."

Lightning Arresters

The subcommittee on lightning arresters, J. R. North, chairman, gave further consideration to arrangements for the proposed joint session at the summer convention and discussed its work on other projects which include: "testing procedure for lightning arresters," "performance characteristics of lightning arresters," "performance characteristics of the various forms of protective gaps," "application of lightning arresters," "specific lightning arrester protection problems," and the preparation of a new standards for "protective gaps."

Chairman North says that the lightning arrester subcommittee has a rather extensive program outlined for the year. He has prepared the following report of the meeting of that subcommittee from reports presented by the sponsors of each of the "sub-groups" on the scope and status of their work.

Testing Procedure for Lightning Arresters—Herman Halperin. This group is determining proper methods and test procedure for ascertaining the condition of lightning arresters in service and as received from the manufacturers. Both station and line type arresters are included. Suitable

Membership—

Mr. Institute Member:

The young engineer looks to the leaders in his profession for guidance and inspiration—for leadership. The American Institute of Electrical Engineers is leadership in organized form; it represents and speaks for all electrical engineers as a group.

An interested and inclusive membership assures you of a strong, representative, and effective organization. You can do yourself and your associate engineers, who are not members, a service by securing their applications or by sending their names to your membership committee.

Vice-Chairman, District No. 5
National Membership Committee

test procedures are being drafted, and arrangements are being made for disseminating this information.

Performance Characteristics of Lightning Arresters—K. B. McEachron. This group is assembling specific and comparative information regarding the 60-cycle and protective characteristics of modern lightning arresters. Present published data regarding arrester characteristics is not on a uniform basis and is, therefore, not directly comparable. It is planned to have the results of this work in shape for submitting as a tentative report at the Institute's 1937 summer convention.

Rod Gaps, Expulsion Gaps, and Deion Gaps—J. J. Torok. The possibility of developing AIEE Standards for gaps and the performance of different types of protective gaps was discussed in considerable detail, and it was decided that the preparation of standards should await the results of the "Manufacturers' Inter-Company Laboratory Group" studies which are now in progress. In the meantime, a summary outlining the status of protective gaps generally is to be prepared so that this information may be readily available for use.

Application of Arresters and Influence of Station Equipment—J. R. North. This sub-group is dealing particularly with the proper application of lightning arresters and the standardization of terminology regarding arrester connections as used with distribution transformers. A memorandum covering this work will be sent out to the members of the subcommittee for consideration within the next few months.

Specific Protection Problems—A. H. Sweetnam. The proper means of protecting various equipment, including constant current transformers, regulators, line switches in open position, etc., is being studied by this sub-group and a memorandum summarizing current practices is to be prepared and distributed as a matter of information.

Proposed Institute Papers. Several papers proposed for presentation before the Institute were discussed. Three papers were proposed as part of a joint symposium on the subject of "Protective Equipment and Insulation Co-ordination," and it was decided that every effort should be made to insure the placing of this joint session on the program for the 1937 summer convention.

Committee on Production and Application of Light

By A. L. Powell, Chairman

Following a review of the work of the committee for the year to date, the chairman pointed out that one technical paper* and several brief contributions† on recent advances in the field of illumination are now awaiting publication in ELECTRICAL ENGINEERING. Inasmuch as the Institute's publication committee has decided that it is expedient to publish more items of general interest, the committee decided to re-establish its policy of supplying a series of short illumination notes so that the editor might have these on hand for use as filler material when occasion arises. Members of the committee were urged to prepare such items on current advances in illumination that come to their attention and submit them to the chairman.

Plans for the session on lighting to be held during the Institute's 1937 summer convention were discussed, and the desirability of avoiding a parallel session was emphasized. There was some discussion also of the various papers proposed for presentation at that session.

* See pages 319–24.
† See pages 302–04.

Committee on Power Generation

By G. M. Armbrust, Chairman

Recent developments in subjects pertaining to the work of the committee were discussed.

It is the opinion of the committee that sufficient new material for papers is available for a session on power generation at the Institute's 1938 winter and the following summer conventions.

The committee will endeavor to arrange symposia covering 2 or 3 subjects such as "superimposed units, their economic advantages and justification," and "parallel operation of power plants and interchange of power over transmission systems."

Committee on Research

By W. B. Kouwenhoven, Chairman

This meeting was attended by 18 members. F. M. Farmer reported that funds had been raised for carrying on the investigation on the "stability of impregnated paper insulation" under the direction of Doctor J. B. Whitehead of Johns Hopkins University. He also reported that the work had been started December 1. The supervisory committee co-operating in this investigation consists of H. H. Race, *chairman*, General Electric Company, Schenectady, N. Y.; R. W. Atkinson, General Cable Corporation, Perth Amboy, N. J.; W. F. Davidson, Brooklyn (N. Y.) Edison Company; R. J. Wiseman, Okonite Company, Passaic, N. J.; and K. S. Wyatt, Detroit (Mich.) Edison Company. This committee reported that it had met with Doctor Whitehead and had unanimously agreed to a definite plan of procedure in carrying out the investigation. Mr. Farmer then reported on the status of the funds for the "investigation in the field of electric shock." He stated that the necessary funds had not been fully raised and that the balance is expected to be available within a short time.

Mr. Farmer also reported on the list of research projects that the research committee has circulated in the past, which list he is now revising. He especially requested the members of the committee to furnish him with suggestions; suggestions from others also are welcome. He reported that the previous lists had proved very useful.

A discussion followed of the methods by which members of the committee could best co-operate with their local Institute Sections. It was decided that each national committee member should offer his services to the chairman of his local Section.

The Committee decided to hold a session at the Institute's 1937 summer convention; 4 papers were proposed for this meeting.

The committee also discussed the question of rural electrification and the problems that exist in that field. K. K. Paluev presented an excellent summary of the economic features of rural electrification. The chairman was instructed to present this to the newly appointed special committee on Institute activities.

Electronics Subcommittee

By H. M. Turner, Chairman

At the meeting of this subcommittee, which is a joint subcommittee of several of the Institute's technical committees, further consideration was given to plans for the 1937 summer convention. It is hoped that the electronics subcommittee will have at least one formal paper (preferably from the Milwaukee, Wis., region) and a conference on electronics with emphasis on industrial applications. The details will be worked out with the convention committee in the near future.

Preliminary plans were made looking toward a rather ambitious program for the AIEE winter convention in 1938. It seems likely that 2 sessions will be required to cover adequately the various phases of electronics, and there probably will be a conference which will permit a more complete and informal discussion of points brought out in the formal presentation. The electronics subcommittee will work with other committees in bringing into focus electronic developments and applications and in unifying them for the benefit of the Institute membership. It will continue the symposium idea that was so successful 2 years ago, but on a somewhat different basis.

Several subjects that have been proposed were considered from the standpoint of their suitability for discussion at the Institute's 1938 winter convention.

Group III of Subcommittee on Conductors, Towers, and Wood Poles

By Edwin Hansson, Chairman

This was a routine meeting of this group, which is one of 3 groups of the subcommittee on conductors, towers, and wood poles, of the Institute's power transmission and distribution committee. Group I is concerned with towers; group II with wood poles, and group III with conductors. Group III was established for the purpose of studying particularly the question of vibration in transmission line conductors, and to establish satisfactory endurance limits. This work is progressing.

Transformer Subcommittee

By I. W. Gross, Chairman

Transformer standards came up for extensive discussion at the meeting of this group, which is a subcommittee of the Institute's committee on electrical machinery. The sectional committee on transformers of the American Standards Association for some time has been preparing, and now is about to issue, a report on a proposed American Standard on power transformers that is scheduled to embrace the AIEE standard "transformers, induction regulators, and reactors (AIEE No. 13), the AIEE publication "Recommendations for the Operation of Transformers" (AIEE No. 100), and the AIEE proposed "Test Code

or Transformers." The AIEE transformer ubcommittee is keeping closely in touch vith this development, co-operating with he ASA sectional committee on transormers, and expects to keep in touch with he situation until such time as the exected reports shall have run the gamut of volution and emerged in final form.

With reference to present impulse tests, he subcommittee unanimously agreed to lter the method of designating impulse roltages as used in the impulse testing of ransformers—from inches-of-gap to kiloolts—without in any way changing the nagnitude or character of the tests. This s a change in terminology only, leaving est procedure unchanged.

To study and later to recommend pracical methods for the drying out of transormers in the field, a subcommittee group as been set up. Recognizing that circumtances frequently prevent the shipment of lamaged apparatus from the field to laboraories, repair shops, or other concentration oints fully equipped with rehabilitation quipment, and recognizing also the limitaion of equipment and specially trained ersonnel in the field, the subcommittee's desire is to establish specifications of practical procedure that will obviate the possibility of damage to transformers that would result from exceeding safe temperature limits during the dry-out period.

To bring up to date the information concerning impulse strength of transformers, a subcommittee technical paper was proposed to give full consideration to this as well as to other related phases of the general problem of insulation co-ordination.

Methods of making front-of-wave impulse tests on transformers were discussed at some length. Consensus of opinion, however, was to the effect that further study is required before any standard could be promulgated.

The problem of establishing, in terms of the normal clearance of the bushing alone, minimum limits of acceptable (or safe) mechanical clearance between bushing terminals and case or other nearby integral parts of a transformer was discussed and assigned to a sub-group for further study and later report.

Comments and suggestions pertaining to any of the foregoing points are solicited by the subcommittee.

Reports of 4 Technical Conferences Held During the Winter Convention

TO PROVIDE opportunity for the inormal "round-table" discussion of techical subjects of a specialized nature, 4 technical conferences" were held during he Institute's 1937 winter convention, nder sponsorship of 3 technical committees nd 1 subcommittee. Brief reports of these onferences are presented here. These reorts have been prepared by the presiding fficers of the respective conferences, except or the conference on test codes for rotating nachines, which was prepared by the chairnan of the sponsoring technical committee.

ducation

By O. W. Eshbach, Chairman

This morning-long round-table conference ponsored by the Institute's committee on ducation drew an attendance of more than 0 committee members and other interested ersons, taxing the facilities of the board oom where the meeting was held.

Although several different subjects perining to the committee's work were enered for discussion, the major portion of the me was devoted to a general discussion oncerning some of the many factors inolved in the current program of the Engieers' Council for Professional Development icident to the accrediting of engineering urricula in the principal educational instituons in the United States. Recent experices incident to this accrediting program the New England and Middle Atlantic reas were discussed at length, and special tention was given to an informal outline nd explanation presented by Doctor A. B. ewman covering the long-established acediting practice of the American Institute Chemical Engineers.

Concerning the question of what constitutes adequate and otherwise acceptable "minimum standards" of engineering education, the general consensus of opinion was that this highly ramified subject presented many related aspects such that there can be no written specification but the judgment of experienced people must prevail.

The committee discussed its plans for participation in the program of the Institute's forthcoming summer convention, and laid definite plans for a 1938 convention program appointing a "steering committee" consisting of O. W. Eshbach, chairman of the committee on education; Dean J. W. Barker of Columbia University; and Professor Robin Beach, head of the department of electrical engineering, Brooklyn Polytechnic Institute.

Network Analysis and Synthesis

By Edward L. Bowles, Chairman

At this conference, which is the second of its type to be sponsored by the Institute's committee on communication, the subject of special network problems that have arisen in connection with the design of radio receivers was presented for discussion as follows:

1. Sidelights on the Multiplex Antennaplex System, by V. D. Landon (this subject deals with filters, amplifiers, and transformers involved in the operation of an antenna system over a wide range of frequencies).
2. Constant-*k* Multitransformer Filters for Covering a Wide Range of Frequencies, by H. A. Wheeler.
3. Driving a Filter From a Reactive Generator, by H. A. Wheeler.
4. The Use of the Mu-Beta Diagram in the Analysis of Feed-Back Circuits, by H. F. Mayer.
5. The Properties of Directive Mutual Reactance Obtained by the Use of Vacuum Tubes, by H. A. Wheeler.

The presentation elicited a very wholesome discussion which was entered into freely by the many individuals whose work dealt with problems in or relating to the field of radio receiver design. From the observers point of view, it was gratifying to see such freedom of discussion and apparent lack of hesitation in the expression of opinion.

The subject of the program quite naturally led to the conclusion that very soon the field of network theory will be generally recognized to include active circuit elements, such as vacuum tubes, and other general circuit elements as, for example, the already applied piezo-electric crystal, and

A group of alumni of the University of Illinois attended the smoker held during the Institute's 1937 winter convention, including 11 members of the class of 1909 all of whom had not been together at one time since graduation. Left to right, seated: H. A. McCrea (A'23, M'30) Boston, Mass.; E. C. Nein, New York, N. Y.; D. A. Henry, New York; P. M. Farmer (M'19) New York; and R. E. Doherty (A'16, M'27, past-chairman of committee on education) Pittsburgh, Pa.; standing: H. C. Dean (A'26, M'29, chairman of board of examiners) New York; E. D. Doyle (A'09, F'27) Philadelphia, Pa.; A. B. Campbell (A'20, M'24) New York; H. D. Braley (A'18) New York; B. M. Fast, New York; I. W. Fisk (A'10, M'13) New York; W. C. Nein (A'08, M'25) New York; M. E. Reagan (A'20, M'30, chairman of committee on automatic stations) East Pittsburgh, Pa.; H. G. Wood (A'23, M'28) Harrison, N. J.; E. S. Lee (A'20, F'30, past-chairman of membership committee) Schenectady, N. Y.; H. O. Siegmund (A'19, M'27) New York; and H. H. Henline (A'19, M'26, national secretary) New York

that future applications of these newer circuit elements will lead to great departures from what may be termed conventional selective network design.

The substantial attendance at both this conference and the one held during the 1936 winter convention is, it appears, an indication of the worth-while nature of meetings of this character which, if they are continued in a vigorous manner, should serve a very useful purpose in aiding the development and application of network theory through personal contact and free and liberal interchange of ideas.

Sound Measurement

By P. L. Alger, Chairman

Specialists of other organizations, as well as Institute members attended this conference, which was sponsored by the subcommittee on sound of the Institute's standards committee. A draft of a proposed test code for the measurement of apparatus noise was reviewed and approved in final form for submission to interested individuals and organizations for approval and subsequent printing by the Institute. This new code is based upon the already published American Standards for acoustic terminology, sound measurements, and sound level meters (*Z*24.1, *Z*24.2, and *Z*24.3). These standards, however, only define means of measuring the sound level at any single point in space and give no information on how to describe the noise produced by apparatus, which involves taking a number of sound-level readings at different locations around the apparatus, and evaluating the effects of ambient sound level, sound reflections from walls and other parts of the environment, and transmitted vibrations. The new code describes both factory and field test procedures necessary for these purposes, but leaves to the individual manufacturer, industry, or user of apparatus the specification of the number of measurements, distances, and other factors, which may be most suitable in any particular circumstances.

The code should serve a useful purpose in educating both makers and users of apparatus to their separate responsibilities for securing quieter living conditions, and in enabling the various causes of unsatisfactory noise conditions to be more quickly traced and remedied.

Following the discussion on this test code, the question of further activity of the subcommittee on sound was considered briefly. It was decided that the subcommittee should continue its work, chiefly for the purposes of education and organized discussion of noise problems. In this connection, it was suggested that a joint round-table session might be held with the Institute's committee on electrical machinery to discuss questions related to the use of elastic mountings for electric motors and transmitted noise problems.

Test Codes for Rotating Machinery

By J. L. Hamilton, Chairman, Committee on Electrical Machinery

This report gives a brief résumé of the development of test codes for rotating electrical machinery, and presents an outline of the discussion and action taken at this conference, which was sponsored by the committee on electrical machinery. G. A. Waters, chairman of the induction machinery subcommittee, presided. Future activities of the committee in connection with each of the codes are indicated.

In May 1929, the board of directors of the Institute approved a proposal of the standards committee calling for the development of test codes for the principal types of electrical machinery and apparatus. The actual formulation of a series of such codes was then placed by the standards committee in the hands of the committee on electrical machinery. In July 1931 that committee made its first report, submitting "Test Code for Transformers." The "Test Code for Synchronous Machines" was the second, and "Polyphase Induction Machines" the third of the proposed series. A test code for d-c machines is being developed at the present time. That the electrical industry might become fully cognizant of the work that has been undertaken and at the same time obtain a clear picture of the proposed contents of such codes, the standards committee arranged for their publication as reports in pamphlet form.

In order to determine the performance characteristics of electrical machines, methods of testing, or test codes, have been developed and are in common usage. It is the purpose of these test codes to provide in convenient reference form the more generally applicable and accepted methods of conducting and reporting tests of a commercial nature, which apply to the fulfillment of performance guarantees and to acceptance tests. It is not intended that the codes shall cover all possible tests or those of a research nature. It must be recognized that the selection of the most suitable test depends upon local conditions and the degree of precision desired.

The subcommittee on synchronous machines has prepared another preliminary report on a proposed test code for synchronous machines which was printed January 1937 and is available for distribution.

The discussion of test codes for synchronous machines developed some suggested changes which were referred to the chairman of the subcommittee on synchronous machines for consideration and action.

The first preliminary test code on polyphase induction machines was printed and distributed in January 1935. Many valuable suggestions for changes and improvements in this preliminary code have been received and considered; these were incorporated in a report by the subcommittee on polyphase induction machines and were considered at this round-table conference. The conference approved the releasing for publication of the code for polyphase induction machines after the editing committee has completed its work. It has not yet been decided as to whether this test code will be recommended to the standards committee as a second preliminary report or otherwise.

The work on the test code for d-c machines had developed to the point where a few copies of a preliminary report on the proposed code were distributed in January 1937 for use at this conference. Suggested improvements in the preliminary report were referred to the chairman of the subcommittee for consideration and action. The subcommittee's final report will probably be printed as a preliminary report on a proposed test code for d-c machines.

The committee on electrical machinery takes this occasion to draw attention to the value of criticisms based upon experience. Any suggestions looking toward improvement in these codes will be welcome for guidance in the preparation of future editions.

ASTM Standards on Insulating Materials

A compilation of all the standards of the American Society for Testing Materials pertaining to electrical insulating materials has been issued in a 1936 edition which includes a number of revised test methods covering the following: varnishes, solid filling and treating compounds, sheet and plate materials, natural mica, untreated paper, insulating oils, and varnished cloths and tapes. Revised specifications cover friction tape, black bias-cut varnished tape, and asbestos yarns, tape, and roving.

In addition, standards are given also for rubber gloves, rubber matting, electrical cotton yarns, silk and cotton tapes, pasted mica, and slate; also rubber insulating tape, flexible varnish tubing, and electrical porcelain. Test procedures cover thickness testing, impact resistance, thermal conductivity, and resistivity. The 1936 report of committee *D*-9 on electrical insulating materials is included; this report outlines the extensive research and standardization work being carried on by the committee. Copies, in heavy paper cover, can be obtained at $2 each from ASTM headquarters, 260 South Broad Street, Philadelphia, Pa.

Springfield Section Offers Electronic Course

A course of instruction in electron theory, tubes, and circuits is being given under auspices of the AIEE Springfield Section in order to provide an opportunity for acquiring knowledge of an increasingly important subject at reasonable cost. Classes meet weekly, the course covering approximately 18 weeks, and each class is limited to 25. Preference is given to members of the AIEE, but nonmembers are admitted upon the payment of $1 in addition to the regular $10 fee for the course. For the additional fee, nonmembers become local members of the Section for the remainder of the Section year.

The course is planned for beginners in the study of electron theory, but students are expected to have a working knowledge of a-c and d-c theory and electrical-engineering terminology. D. E. Noble (A'32) assistant professor of mechanical engineering at Connecticut Agricultural College, has been chosen as instructor for the course.

)octor Elihu Thomson Honored at Welding Session

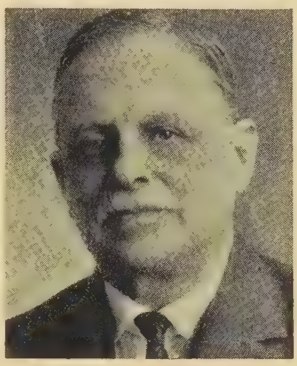
RESENTATION and discussion of the aper "Resistance Welding Circuits" by . L. Pfeiffer (A'21, M'27) constituted the rst item on the program of the session on ectric welding held during the Institute's ecent winter convention. This paper was ublished in the August 1936 issue of LECTRICAL ENGINEERING, pages 868–73. t the conclusion of the discussion, a demon-ration lecture entitled "Some Fundamen-al Phenomena of the Electric Arc" was resented by Doctor C. G. Suits of the re-earch laboratory, General Electric Com-any, Schenectady, N. Y. Following)octor Suits's lecture and the ensuing iscussion, Herman Lemp (A'89, F'13) con-ilting engineer of the Ingersoll-Rand Com-any, New York, N. Y., presented rem-iiscences of Professor Elihu Thomson's indamental invention of electric resistance elding. His address was supplemented by emarks by Albert L. Rohrer (A'87, M'88) etired, Maplewood, N. J., who is said to be ie only living witness of Professor Thom-on's early efforts to develop the resistance-elding art. H. M. Hobart, chairman of ie Institute's committee on electric weld-ig, presided at the session; he was assisted y K. L. Hansen, ex-chairman of the com-iittee on electric welding, and W. E. rawford, a member of the committee for ie past 5 years.

ECTURE BY DOCTOR SUITS

Doctor Suits has supplied the following bstract of the material used in his demon-ration lecture:

Contemporary Arc Theory. The Compton ieory of the electric arc serves as the oundation for the development of the iodern thermal concept of the high pres-ire discharge. Measurements of arc-core emperatures made by several methods, such s (1) from gas density, by X ray absorption VonEngel and Steenbeck), (2) spectro-raphic observations (Ornstein), or (3) by ie velocity of sound waves (Suits), show iat the arc core is a body of gas ionized to degree determined by its temperature of pproximately 5,000 degrees Kelvin. In his high-temperature arc core the current onduction is by a thermal ionization process i quantitative agreement with Compton's ieory in cases where the measurables are nown. On the basis of this picture the ore of an arc in air has the following prop-rties: Its temperature lies in the range f from 4,000 to 7,000 degrees Kelvin; its omposition is of the order of 20 per cent I_2, 25 per cent O, 55 per cent N; partial ressure of electrons is 10^{-4} atmospheres; ie mean density is 0.00003 or approxi-iately $^1/_{30}$th that of air at the same pres-ire and at room temperature; the gas iscosity is approximately 0.0016, which is early as great as that of water at the oiling point; the effective ionization poten-al lies in the range between 8 and 15 olts.

Arcs at Very High Pressures. New arc ata presented in the practically unexplored eld of very high gas pressures. To cover iis range several experimental chambers are employed. Transient arc stability is studied in a very small chamber up to pressures of 50 atmospheres. A second chamber, which employs a window, allows measurements of current, current density, and electric gradient up to 200 atmospheres. A third hydraulic-ram chamber allows measurements of current, voltage, and light quality up to 3,500 atmospheres. It has actually been used with nitrogen up to 1,275 atmospheres (18,800 pounds per square inch). In general, it is found that the current density, electric gradient, and arc luminosity increase with pressure. Probably the most important result of this study is the following correlation: Arcs in various gases and at various pressures develop the same current density and electric gradient at the pressures for which the heat transfer is the same. Thus the arc in hydrogen at one atmosphere should have the same current density and electric gradient as the arc in nitrogen at approximately 100 atmospheres, in agreement with experiment. Using this correlation law, arc properties can be predicted in a pressure range for which the measurements may be difficult or impossible. The generality of the theory awaits more complete measurements, but in the cases of nitrogen and hydrogen the agreement with experiment is as good as the knowledge of heat transfer allows.



Doctor Thomson

Following his talk, Doctor Suits demonstrated some of his results by throwing an enlarged image of an experimental electric arc onto a ground-glass screen so that those in the audience could see.

Experiment 1. This showed the arc between pure carbon electrodes, with an arc length of 3 millimeters, and an arc current of 6 amperes (d-c). From the image projected on the screen, the arrangement and position of the electrodes and the dimensions of the arc column could be seen for comparison with the following experiments.

Experiment 2. For the same electrodes, arc length, and arc current, the arc in hydrogen at a pressure of 1 atmosphere was shown. The much smaller diameter of arc column with resultant increase in current density appeared from the reduced size of the image.

Experiment 3. For the same conditions as for experiments 1 and 2, the arc was shown in commercially pure nitrogen at a pressure of 1 atmosphere. This arc appeared to have characteristics quite identical with those of the arc in air.

Experiment 4. For the same electrode arrangement and current the arc was burned in nitrogen at a pressure of 80 atmospheres. At this pressure the arc cross-section decreased and the current density was nearly as great as in hydrogen at 1 atmosphere. When the pressure was reduced from 80 atmospheres to 1 atmosphere, the continuous increase in arc diameter with decrease in pressure was visible.

In the discussion that followed, the opinion was expressed that the results presented by Doctor Suits are of fundamental importance in the study of the electric arc, and that a published paper reporting those results would prove highly valuable for reference purposes.

TALKS BY MESSRS. LEMP AND ROHRER

The following summary of remarks by Herman Lemp and Alfred L. Rohrer was prepared by Doctor G. E. Claussen of The Engineering Foundation, who attended the session.

Mr. Lemp referred to the Franklin Institute lectures in 1878 by Professor Thomson, in which electrical discoveries were discussed. It was at this time that Professor Thomson commenced experiments leading to the development of electric resistance welding. He discharged a Leyden jar through the secondary of a Ruhmkorff coil. The ends of the primary, being close together, were found to have stuck together as a result of the discharge. Following the lead provided by this experiment, Professor Thomson was able in 1885, to make practical applications of electric resistance welding, as it is now known.

Mr. Lemp then interrupted his remarks to introduce Mr. Rohrer, another former associate of Professor Thomson. Mr. Rohrer made a verbal sketch of the qualities that characterized all of Professor Thomson's work and made him a supreme experimentalist and scientist. Professor Thomson was among the first to become convinced that all metals and alloys are weldable by the resistance process. The Ruhmkorff coil used by Professor Thomson in his early experiments, and having a capacity of 2,000 to 3,000 amperes is still in existence at Thomson's laboratory, Lynn. Mass. Mr. Rohrer concluded his remarks by contrasting the experimental equipment for resistance welding used by Professor Thomson in the eighties with present-day resistance-welding machines of several types used extensively in industry.

After Mr. Lemp had shown slides of resistance-welding equipment, he resumed his reminiscences of the early developments of the Thomson electric resistance welding concern. He presented brief biographies of several engineers who made noteworthy contributions to that development, including the following Institute members: Walter S. Moody (A'06, F'12), Russell Robb (A'93, M'95), G. F. Sever (A'94, F'12), A. R. Everest (A'04, M'04); Messrs. Robb and Everest are deceased. Mr. Lemp referred particularly to several of the outstanding achievements of the Thomson concern in the field of transformer and rotary convertor construction. Among other in-

teresting anecdotes, he recounted the experiences he had in applying electric resistance heating to the local annealing of hardened steel, such as armor plate, for the United States Navy. The process was first applied in the construction of the famous battleship "Oregon" shortly prior to the war of 1898. Mr. Lemp also made it plain that the scope of the activities of the Thomson concern was international.

At the conclusion of Mr. Lemp's talk, those in attendance voted to send the following telegram to Professor Thomson:

"We, members and guests of the American Institute of Electrical Engineers, here assembled, in reviewing the past, present and future of an art created by your vision and perseverance, send greetings to you and the assurance of our appreciation of what your work has meant to industry and the arts, and which in the hands of capable young engineers is bound to become more valuable as time goes by on the foundation laid down by you."

Before the meeting was adjourned, President MacCutcheon spoke briefly, stressing especially the importance of resistance welding to electrical engineers, first, because the process is fundamentally electrical, and second, because the process is very widely used in the construction of electrical machinery.

Usefulness of Tensors Probed at Convention Session

WITH E. E. Dreese (M'25) chairman, electrical engineering department, Ohio State University, Columbus, presiding, more than 100 attended both the morning and afternoon sessions on tensor analysis, held on Tuesday, January 26, during the Institute's recent winter convention. The following 5 papers, all published in ELECTRICAL ENGINEERING, were presented:

1. THE TENSOR—A NEW ENGINEERING TOOL, A. Boyajian. April 1936 issue, pages 856–62.

2. TENSOR ALGEBRA IN TRANSFORMER CIRCUITS, L. V. Bewley. November 1936 issue, pages 1214–19.

3. TENSOR ANALYSIS OF MULTIELECTRODE TUBE CIRCUITS, Gabriel Kron, November 1936 issue, pages 1220–42.

4. DYADIC ALGEBRA APPLIED TO 3-PHASE CIRCUITS, A. Pen-Tung Sah, August 1936 issue, pages 876–82.

5. COMPLEX VECTORS IN 3-PHASE CIRCUITS, A. Pen-Tung Sah, December 1936 issue, pages 1356–64.

Following the formal presentation of the papers, the sessions were featured by enthusiastic discussions by members and some guests who were invited, because of their particular qualifications, to present informal discussions on the papers. Among the invited discussers was Doctor Banesh Hoffman, of the Institute for Advanced Study, Princeton (N. J.) University, who discussed the papers from the point of view of the mathematician, showing the simplicity of the tensor method by assuming a simple hypothesis in the physics of motion and developing it into a tensor expression. He pointed out the advantages of tensors in distinguishing physical phenomena by avoiding the use of specific coordinate axes and reference frames; however, he expressed the belief that at present electrical engineers are not using tensors as they are known in the realm of pure mathematics, but are using a modified form of tensor theory.

Doctors Oswold Veblen and H. W. Tucker, also of the Institute of Advanced Study, Princeton University, continued the discussion of the purely mathematical aspect of tensors. Doctor Veblen spoke briefly about the controversial aspect of tensor analysis and its introduction as an engineering tool, comparing the present controversy to the disputations aroused by the introduction of quaternions as an analytical aid. He stated that tensor analysis is very valuable to certain branches of science, but that it should not be forced upon the engineer as a universal instrument of analysis, for it is not the most easily applicable method for all types of problems. Doctor Tucker demonstrated the applications of some of the abstract processes of topology to the analysis of electrical circuits.

Professor Karl L. Wildes (A'21, M'29) associate professor of electrical engineering at Massachusetts Institute of Technology, Cambridge, compared the methods of symmetrical components and dyadic algebra in the analysis of unbalanced polyphase circuits, pointing out an advantage in the use of dyadic algebra for solving 3-phase circuits with unbalanced impedances. Professor Wildes asserted that engineers should not be too eager to adopt the method of tensors until its field of usefulness is more clearly defined, because the general application of method may be more obscure and devious than the methods now in use.

After 2 sessions on tensors: E. E. Dreese (left) of Columbus, Ohio, who presided, and K. L. Wildes of Cambridge, Mass., one of the discussers

W. E. Byrne, of Virginia Military Institute, outlined briefly his experiences in attempting to teach the theory of tensors to a special class of senior students. He expressed a need for closer co-operation between the teacher of mathematics and the practicing engineer.

W. H. Ingram, New York, N. Y., based his discussion upon 2 premises: (1) tensors have not been introduced in electric-circuit theory to date; and (2) there is no necessity for using tensors in circuit analysis. He contended that the term "tensor analysis," as used in electrical-engineering literature, is a misnomer and, moreover, that tensors have no direct application in electrical-engineering problems.

Professor M. G. Malti (M'34) of Cornell University, Ithaca, N. Y., discussed briefly the need for new methods of analysis to deal with the complexities of modern electrical-engineering problems and the suitability of tensors in filling that need. He predicted that the tensor method will be found useful in so many branches of electrical science that its universal adsoption is inexorable, although it may be slow in finding such acceptance. Professor Malti recalled that many engineers bitterly contested Heaviside's operational methods at the time of their introduction, but that those methods have become so widely useful that they can be ignored no longer.

L. V. Bewley (A'27) in his closing discussion emphasized an opinion expressed in his paper: that the tensor method, although extremely flexible, is an inefficient engineering tool, because most problems do not require the mathematical power obtainable by means of tensors. By way of substantiating this assertion, Mr. Bewley described the results obtained by a group of advanced engineering students in determining the best method of analysis in the solution of a great variety of electrical-engineering problems. Each problem was first analyzed to determine the most suitable method of attack, solved by the method chosen, and recorded. Most problems were found to be most easily solved by the conventional vectorial methods; only a relatively small number were advantageously solved by the use of the tensor method.

Following a brief closing talk by P. L. Alger (A'17, F'30) of the General Electric Company, Schenectady, N. Y., who was one of the chief promoters of the tensor sessions, the afternoon session was adjourned by Chairman Dreese; however, several informal conferences were formed for the further pursuit of unfinished problems and arguments. According to Chairman Dreese, the sessions were notably combined meetings of engineers and mathematicians, in which the free interchange of ideas served to inform the mathematicians of new applications of a method of reasoning with which they are already familiar, and to suggest to the engineers some further applications of the tensor method, some necessary revisions in nomenclature and symbols used in engineering papers, and some improvements to provide a more rigorous mathematical treatment of problems involving the use of tensors.

IES Moves Offices. General offices of the Illuminating Engineering Society have been moved from the Engineering Societies' Building to the New York Life Insurance Company Building, 51 Madison Avenue, New York. All communications to the society should be sent to room 2100 at the new address.

Conference Held by Student Branches Committee

Some 40-odd committee members, Student Branch counselors, and other interested persons attended a luncheon conference of the Institute's Student Branches committee, held at the Town Hall Club in New York, N. Y., January 27, 1937, during the recent winter convention. Among those present were Past-President (1902–03) Charles F. Scott of New Haven, Conn.; Past-Vice-President W. H. Timbie of Cambridge, Mass.; Vice-President C. Francis Harding of Lafayette, Ind.; Director R. W. Sorensen of Pasadena, Calif.; and Director F. Ellis Johnson of Columbia, Mo., who as chairman of the Student Branches committee presided.

Chairman Johnson reported that the organization of 3 new Branches had been authorized on January 26, by the Institute's board of directors in accordance with the recommendation of the committee on Student Branches: Tulane University, New Orleans, La.; Northwestern University, Evanston, Ill.; and Columbia University, New York N. Y.

With reference to the organization of future Student Branches, a question was raised concerning the possible influence of the current program of the Engineers' Council for Professional Development in accrediting engineering curricula. Two schools of thought on the subject were evident: (*a*) That the authorization of Branches should not be dependent upon the accrediting of certain technical curricula; and (*b*) that no Branch should be authorized in institutions where electrical engineering curricula had not been accredited. The consensus of opinion was to the effect that for the present, and until ECPD's accrediting program has been carried further, there would be no change in the committee's basis for considering the organization of new Student Branches.

The perennial subject of student technical papers, particularly with reference to District and national prize competition and rules governing such competitions, came up for extended discussion. The general consensus of opinion seemed to be that the question of a proper basis for national grading of student papers "is not yet satisfactorily settled."

Student Branch counselors came in for self-discussion, in connection with successful and effective conduct of Branch activities. Emphasized during the discussion was the fact that the Branch counselorship is "an important position involving certain definite responsibilities as well as certain privileges," and that the office should not be held by any one man for any great length of time, but should be passed around among available faculty members so that full benefit might be derived from "new blood."

Director F. Ellis Johnson, of the University of Missouri, Columbia, chairman of Student Branches committee presiding

Student leadership, and the training of students for leadership, was believed by many to be one of the most important functions and opportunities of the Student Branch. It was strongly opined that the Branch "should be operated as a training ground for leadership," and that consequently as many students as possible should have the opportunity of serving as Branch officers and otherwise actively participating in the development and conduct of Branch affairs.

Group at head table at conference of Student Branch counselors; left to right: Past Vice-President W. H. Timbie, Massachusetts Institute of Technology, Cambridge; Past-President Chas. F. Scott, Yale University, New Haven, Conn.; Director F. Ellis Johnson (chairman) University of Missouri, Columbia; W. E. Wickenden, Case School of Applied Science, Cleveland, Ohio; Past Vice-President H. V. Carpenter, State College of Washington, Pullman; T. F. Ball, University of South Carolina, Columbia; A. B. Newman (member of American Institute of Chemical Engineers) Cooper Union, New York, N. Y. In the foreground is W. R. Work, Carnegie Institute of Technology, Pittsburgh, Pa.

Executive Committee of Southern District Meets

A meeting of the executive committee of the Institute's Southern District (Number 4) was held at Chattanooga, Tenn., December 5, 1936. The following attended:

W. W. Hill, counselor, Alabama Polytechnic Institute Branch
K. L. Dillon, secretary, Alabama Section
C. W. McCracken, Birmingham, Ala.
J. M. Flanigen, secretary, Atlanta Section
Stanley Warth, chairman, Louisville Section
W. A. Smith, chairman, Florida Section
E. A. Corum, chairman (now past-chairman), Memphis Section
J. E. Jackson, chairman, Virginia Section
A. P. Farrow, secretary, East Tennessee Section
Chase Hutchinson, chairman, East Tennessee Section
E. E. George, vice-chairman, East Tennessee Section
F. E. Johnson, secretary, New Orleans Section
W. J. Seeley, student counselor, Duke University Branch
Mark Eldredge, vice-president, Southern District
R. F. Crenshaw, secretary, Southern District

The District co-ordinating committee to function according to section 33 of the AIEE by-laws was selected as follows: Mark Eldredge and R. F. Crenshaw, *ex-officio;* F. W. Russell, Louisville, Ky.; H. N. Pye, Atlanta, Ga.; W. W. Hill, Auburn, Ala.; C. W. Ricker, New Orleans, La.; and K. L. Dillon, Birmingham, Ala.

Activities of the Sections were discussed by Vice-President Eldredge, following which the delegates representing the various Sections in the District gave brief outlines of the activities of their respective Sections. Mr. Hill summarized the student Branch activities, and mentioned that a District student conference is to be held in April at Auburn, Ala., with representatives from other colleges attending.

Members of the committee next partook of a delightful luncheon, arranged by Mr. George, as guests of the Tennessee Electric Power Company. Following the luncheon, Edwin D. Wood, director and general superintendent of the Louisville (Ky.) Gas and Electric Company, was unanimously nominated as the District candidate for vice-president to succeed Mr. Eldredge. E. E. George was chosen to represent the District on the national nominating committee.

The monthly publication of the Institute, ELECTRICAL ENGINEERING, was the next topic for discussion. After considerable discussion of various phases of the publication, it was unanimously voted that the committee send the following resolution to headquarters:

That in order to increase interest and value to the students and memberships at large, the journal should include a summary of each article being approximately 10 per cent of the length of the article and written by the technical staff of the journal, which would outline the paper or article for most readers without including the subject matter in a theoretical nature. Also that more illustrations and practical applications be presented whenever possible.

Vice-President Eldredge gave a brief account of the discussion at a recent meeting of the Institute's board of directors on the branching out of electrical engineers into fields beyond electrical engineering, such as economics, to encourage electrical engineers to study and be actively engaged in other subjects of world interest. It was suggested that every effort be made to stimulate employers to consider an applicant's activity in engineering organizations

when evaluating his qualifications in addition to education and practical experience. The importance of engineers in executive positions in actively engaging in the affairs of engineering organizations was emphasized.

Following discussion of other routine matters, the committee was taken on an inspection tour through the dispatching headquarters of the Tennessee Electric Power Company.

Acoustical Terminology Standard Completed by ASA

A standard acoustical terminology for engineers which is intended to eliminate confusion in motion picture, radio, and building fields has just been completed, according to an announcement by the American Standards Association. This standard is the work of engineers, musicians, manufacturers, and scientists, and has been 4 years in development. According to Leopold Stokowski, a member of the committee in charge: "In the America of the future radio and motion pictures will be important in developing our civilization. For this we need a complete understanding between engineers and musicians." The new standard is expected to achieve this "understanding."

The committee gives a broader meaning to the word "noise," now defined in terms of the listener as an "unwanted" sound rather than in terms of the sound itself. A section of the standard deals with architectural acoustics. Another section that provides standard terms for the measurement of hearing will be useful to the medical profession and to manufacturers of aids for the partially deaf. Other parts dealing with the conversion of sound to electrical energy and with acoustic transmission systems will be of particular value in motion picture and radio work.

A separate section for music brings engineers and acoustical experts into agreement with musicians on a basic standard pitch, the importance of which can be judged by the fact that an increase of only 4.14 per cent in pitch carried out through the entire keyboard of a piano would throw an additional strain of approximately half a ton on the framework of the instrument.

Standards for reference and intensity levels for sound measurement and for characteristics of measuring instruments have already been completed.

Lamme Medal Awarded to Frank Conrad

The 1936 Lamme Medal of the AIEE has been awarded to Doctor Frank Conrad (A'02) assistant chief engineer of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., "for his pioneering and basic developments in the fields of electric metering and protective systems." The medal and certificate will be presented to him at the annual summer convention of the Institute, to be held in Milwaukee, Wis., June 21–25, 1937. A biographical sketch of Doctor Conrad may be found in the "personals" columns of this issue.

The Lamme Medal was founded as the result of a bequest of Benjamin G. Lamme, chief engineer of the Westinghouse Electric & Manufacturing Company, who died on July 8, 1934; this bequest provides for the award by the Institute of a gold medal (together with a bronze replica thereof) and a certificate annually to a member of the AIEE "who has shown meritorious achievement in the development of electrical apparatus or machinery," and for the award of 2 such medals in some years if the accumulation from the funds warrants. A committee composed of 9 members of the Institute awards the medal. Previous recipients of the award have been: 1928, A. B. Field (A'03, F'13); 1929, R. E. Hellmund (A'05, F'13); 1930, W. J. Foster (A'07, F'16); 1931, Guiseppe Faccioli (A'04, F'12, deceased); 1932, Edward Weston (A'84, M'84, past-president, deceased); 1933, L. B. Stillwell (A'93, M'92, F'12, member for life, past-president); 1934, H. E. Warren (A'02), and 1935, Vannevar Bush (A'15, F'24).

Mr. Lamme made similar bequests to the Society for the Promotion of Engineering Education and Ohio State University, providing in the former for the annual award of a medal "for accomplishment in technical teaching or actual advancement of the art of technical training," and in the latter for the annual award of a medal to a graduate of Ohio State University in any branch of engineering for meritorious achievement in engineering or the technical arts. The 3 organizations adopted a common obverse for their medals, and each prepared a suitable reverse.

Special Committee on Dues Recommends No Change

FOR several years a special committee of the AIEE has studied the matter of dues and membership grades with particular reference to the dues of Associates.

A final report was presented to the AIEE board of directors on January 26, 1937, recommending that no changes be made in dues or in membership grades at this time. The report was acted upon favorably by the board at this meeting.

An intensive study over a long period forced the committee to come to this conclusion. Any endeavor to place a time period in any membership grade with a change of dues involved the same fundamental criticisms that have been applied to the present rules. Any endeavor to make one fee for each grade without a time period involves increasing the dues in other grades or a penalty on the admission of young engineers.

An endeavor to get uniformity in grades and dues for the founder societies was made without success and a study of the accompanying tables shows that dues and grades for the AIEE are in line with the practices of these societies.

A statistical study of dues and members and of the effect of the increase in dues for 6-year Associates gives no evidence that this increased fee acts to deprive the Institute of members.

The membership on May 1, 1936 (including those who were in arrears for only one year on that date) developed dues charges to a total of $192,085, and the grade classifications were as follows:

691 Fellows @ $20	$ 13,820
3,829 Members @ $15	57,435
5,258 6-year Associates @ $15	78,870
4,196 less-than-6-year Associates @ $10	41,960
Total	$192,085

To revert to the former practice of charging all Associates $10 dues would have reduced the above total to $165,795, a difference of $26,290.

The membership committee of the New York Section recently made a recommendation that the dues of all Associates, without regard to length of membership, be fixed at $12.50. If this provision had been in effect on May 1, 1936, the total dues charges would have been $189,430 or $2,655 less

Table I—Entrance Fee and Dues of Engineering Societies

Grades	ASME Entrance Fee	ASME Dues	ASCE Entrance Fee	ASCE Dues	AIME Entrance Fee	AIME Dues	AIEE Entrance Fee	AIEE Dues
Fellow	$30	$25	$	$ (b)	$	$	$20	$20
Member	25	20	30	20	20	15	15	15
Associate member			25	20				
Associate	25	20			20	15	10	(f) 10
Affiliate			30	20				
Junior member	10	(a) 10	10	(c) 10		(e) 10		
Junior foreign affiliate						5		
Student members		3		(d)		2		3

(a) Dues of junior member grade increased to $20 after 6 years of membership.
(b) All members located within district number 1 (i.e., territory within 50 miles of New York City) pay $5 more than the amount indicated for each grade.
(c) Membership ceases at 33 years of age, unless previously transferred to grade of associate member.
(d) Membership in a student chapter includes privileges of special subscription rates to society publications.
(e) Dues charge of $10 obtains only for first 6 years after election or until reaching age of 33; thereafter charge is $15.
(f) Increased to $15 after completion of membership term of 6 years.

le II—Associates Resigned and Dropped From May 1, 1927 to May 1, 1930

	6-Year Associates		Associates	
	Number	Per Cent	Number	Per Cent
1, 1927:	6,101		8,664	
ropped	425	7.0	739	8.5
esigned	205	3.3	234	2.7
Total	630	10.3	973	11.2
1, 1928:	6,037		8,401	
ropped	395	6.5	707	8.4
esigned	156	2.6	173	2.1
Total	551	9.1	880	10.5
1, 1929:	6,303		7,756	
ropped	295	4.7	566	7.3
esigned	197	3.1	167	2.1
Total	492	7.8	733	9.4
1, 1930	6,664		7,069	

le III—Associates Resigned and Dropped From May 1, 1933 to May 1, 1936

	6-Year Associates		Associates	
	Number	Per Cent	Number	Per Cent
1, 1933:	6,671		5,747	
ropped	861	12.9	801	13.9
esigned	315	4.7	188	3.3
Total	1,176	17.6	989	17.2
1, 1934:	6,149		4,659	
ropped	731	11.9	775	16.6
esigned	174	2.8	88	1.9
Total	905	14.7	863	18.5
1, 1935:	5,632		4,225	
ropped	326	5.8	379	9.0
esigned	137	2.4	107	2.5
Total	463	8.2	486	11.5
1, 1936	5,679		4,299	

n the total actually charged in our rec-s. It seems to the committee that the blishment of dues of all Associates at 50 would materially reduce the number ecent graduates applying for admission.

n table I data are shown regarding the s, and special arrangements applicable to n, of the 4 large national engineering so-ies. In this tabulation it may be noted the dues of the American Institute of ing and Metallurgical Engineers do not er greatly from those of the AIEE, and the dues of the American Society of l Engineers and The American Society Mechanical Engineers are materially er. It is also significant to note that the AIME and ASME have adopted visions similar to that of the AIEE, ad-ing the dues charge to the junior mem-grade after 6 years or after the age of 33 he AIME. The ASME no longer ter-ates membership in the junior grade at age of 35 as was the practice until a few s ago. It seems obvious that on the s of any comparison with the dues of the r societies the Institute's arrangements ear favorable.

n tables II and III is information regard-the numbers of Associates who resigned who were dropped during 3 fiscal years nning May 1, 1927, and in 3 fiscal years nning May 1, 1933, in order that the results both during and before the depression may be noted.

The percentages of Associates of less than 6 years standing who were dropped are higher in all 6 years than those of Associates of more than 6 years standing. The percentages of Associates of more than 6 years standing who resigned were higher in 5 of the years than the percentages of those of less than 6 years, but, of course, the figures for resignations are far below those of the numbers dropped. Hence, the total percentages dropped and resigned are higher for the less-than-6-year Associates in 5 of these 6 years.

Table IV is included to give some very recent figures regarding Associates who were delinquent. These do not indicate any adverse effects of the change in dues.

The committee has had opportunities to study during the past few years a great many tables dealing with these matters. The tables presented herein seem to be representative. After watching with the greatest care the results of the change in dues of Associates since the adoption, the committee concludes that the increase has had no appreciable effect upon the losses from the membership.

It seems essential to offer some reduction in dues to recent graduates for a few years. Since they constitute a high percentage of Associates admitted, it seems unnecessary and undesirable to make provisions for different dues for 2 groups, one including the recent graduates and the other including any other Associates admitted.

Some members have said that on account of the psychological effects of the present arrangements some kind of a change should be made. Any other plan involving a change in dues after the lapse of a certain period of time would, in the opinion of the committee, cause fully as much dissatisfaction as does the present plan. The types of members who will be a credit to the Institute seldom object, and we should not be unduly influenced by the "kicker" class. The committee has not heard any good reason why Associates should not after 6 years pay their fair share of the cost of conducting Institute activities.

A printed sheet has for 5 or 6 years been sent to all Associates at the time they reach the end of the 6-year period and are called upon to pay the dues of $15. Since headquarters has been supplying this information directly to the individuals concerned there have been fewer complaints than before.

Table IV—Associates Delinquent on July 1, 1935 and on July 1, 1936

	6-Year Associates		Associates	
Membership on	Number	Per Cent	Number	Per Cent
July 1, 1935	5,499		4,472	
Including members who owe dues to				
May 1, 1934	370	6.7	373	8.4
May 1, 1935	562	10.2	455	10.2
July 1, 1936	5,571		4,650	
Including members who owe dues to				
May 1, 1935	228	4.1	263	5.7
May 1, 1936	485	8.7	400	8.6

It seems to the committee that there are obvious advantages in the flexibility of the provisions for Associates who are in the 3 large groups mentioned in paragraph 6 of the printed information.

In view of the thorough study made of the effects of the present system and of all possible suggestions for changes, the committee agreed to the conclusion that no changes be made at this time.

The special committee to consider dues of associates and related matters was appointed in 1932; the following served on the committee: L. W. W. Morrow (chairman 1935–37), H. H. Barnes, Jr. (chairman 1932–33), H. Goodwin, Jr., W. H. Harrison, J. Allen Johnson (deceased, chairman 1933–35), E. S. Lee, and E. B. Meyer (deceased).

Comments Invited on ECPD Recognition Report

The report of the committee on professional recognition of Engineers' Council for Professional Development, presented at the annual meeting of that organization held on October 6, 1936, was published in the December 1936 issue of ELECTRICAL ENGINEERING, pages 1390–92, with a statement that official action by ECPD on the recommendations included in the report had been deferred pending further consideration at a future meeting, and that comments on these recommendations were invited.

This report was discussed briefly at the meeting of the AIEE board of directors held during the Institute's 1937 winter convention, and was referred to the committee on economic status of the engineer for report to the board. Professor R. W. Sorensen, California Institute of Technology, Pasadena, chairman of that committee, requests that AIEE members read the report and send their comments directly to him.

AIEE Members Receive Eta Kappa Nu Awards

Many prominent members of the AIEE were present at a meeting of the Eta Kappa Nu Association on January 25, 1937, at New York, N. Y., when F. M. Starr (A'30) central station engineer of the General Electric Company, New York, N. Y., received the award in the 1936 Eta Kappa Nu recognition of "outstanding young electrical engineers." His name will be engraved on a trophy to be placed at AIEE headquarters; a small replica of the trophy was presented to Mr. Starr. Certificates of honorable mention were presented to P. L. Bellaschi (A'29, M'34) Westinghouse Electric & Manufacturing Company, Sharon, Pa.; E. W. Boehne (A'29) General Electric Company, Philadelphia, Pa.; A. C. Seletzky (A'29, M'35) Case School of Applied Science, Cleveland, Ohio; and C. G. Veinott (A'28, M'34) Westinghouse Electric & Manufacturing Company, Springfield, Mass. An announcement of the awards and biograph-

K. M. Winkworth

A group at the presentation of the Eta Kappa Nu awards as "outstanding young electrical engineers"; from left to right, A. C. Seletzky and E. W. Boehne, 1936 honorable mention; F. M. Starr, 1936 winner; C. A. Faust, president of Eta Kappa Nu Association; C. G. Veinott and P. L. Bellaschi, 1936 honorable mention

ical sketches of those receiving them were published in the January 1937 issue of ELECTRICAL ENGINEERING.

Charles F. Scott (A'92, F'25, HM'29, past-president) spoke on "Opportunity and Young Engineers," calling on F. M. Feiker (M'34) of American Engineering Council for a few words. Vladimir Karapetoff (A'03, F'12, Life Member), to illustrate his subject "Art and Culture for the Engineer," played selections on the piano. Other Institute members taking part in the ceremonies were C. A. Faust (A'35) toastmaster, R. I. Wilkinson (A'35), M. S. Mason (M'31), E. S. Lee (A'20, F'30, director), and Morris Buck (A'05, F'23).

Mr. Starr delivered an address, "Let's Take a Look at Ourselves." Other addresses were "The Young Engineer and His Success" by Mr. Bellaschi, "Engineering Appreciation" by Mr. Boehne, "Broken Bones" by Doctor Seletzky, and "Achievement, Perspective, and Balance" by Mr. Veinott. Doctor Seletzky described apparatus, developed in collaboration with Doctor W. McGaw of Western Reserve University, that is intended for use in studying the progress of "knitting" or healing of fractured bones. An inertia-operated crystal vibrator driven by an oscillator is applied to one end of the fractured member, and an inertia-operated pickup of the crystal type, connected through an amplifier to an output meter, is applied to the other end of the fractured members so that the fracture is between them. The sound-intensity measurement obtained is compared with the measurement obtained on the "symmetrical mate" of the fractured member (that is, the right leg if the left leg be the broken member), and the ratio indicates the degree of "knitting," unity being perfect. The method is said to be of exceptional value in so-called "delayed unions" where the X ray may not reveal the true condition.

Federal Power Commission Report. In the sixteenth annual report to Congress, submitted by Frank R. McNinch, chairman; *Basil Manly*, vice-chairman; Herbert J. Drane, Claude L. Draper, and Clyde L. Seavey, commissioners, the Federal Power Commission reports "increased activity in the various functions which have been performed for 16 years, and marked progress in the new activities entrusted to the commission by Congress in the Federal Power Act of 1935." The report, which is for the fiscal year ended June 30, 1936, and with additional activities to December 1936, consists of a 68-page paper-covered pamphlet, 6 by 9 inches, and may be obtained at 10 cents per copy from the Superintendent of Documents, Washington, D. C.

North Eastern District to Meet in Buffalo May 5-7

Buffalo, N. Y., will be host to a 3-day meeting of the North Eastern District with headquarters in the Statler Hotel, May 5–7, 1937. Tentative arrangements indicate that an interesting program, consisting of 3 or more technical sessions, a student technical session, entertainment, and inspection trips, will take place. Arrangements are to be made for a dinner on Thursday evening with a popular lecture afterward; there will also be a dance in the hotel on that evening.

Buffalo and its environs offer opportunities for many inspection trips among a variety of industries. There are the various steel mills, the Ford Motor Company, and the Huntley station as well as several other stations of the Buffalo General Electric Company. In addition, arrangements may be made for a golf tournament, and the city offers many attractive types of amusement.

Further details will be announced when made available.

Consulting Engineer Dies. J. F. Max Patitz, chief consulting engineer of the Allis-Chalmers Manufacturing Company, Milwaukee, Wis., died January 3, 1937. He was associated with the company for more than 51 years, during nearly 26 of which he served as consulting engineer. Mr. Patitz was born at Mugeln, Saxony, in 1866, and entered the employ of the E. P. Allis Company in Milwaukee in 1885. In 1901, when that company became part of the Allis-Chalmers Company, he was placed in charge of the building of steam engines and con pressors. Mr. Patitz began his studies parallel operation of a-c generators as earl as 1900. He also made studies of critic speeds and of vibration in high-speed ma chines, and was an authority on intricat mathematical calculations connected wit the design of machinery. Mr. Patitz wa a member of The American Society of Mc chanical Engineers, the Society of Automo tive Engineers, and the Verein Deutsche Ingenieure.

Tour of European Laboratories Planned

Industrial leaders to the number of 10 from all parts of the United States ar expected to participate in a tour of Europea scientific laboratories which is being planne by the division of engineering and industria research of the National Research Council An advisory committee to co-operate i the planning has been appointed.

The tour will provide an opportunit to observe methods of outstanding researcl laboratories in Europe representing 1 major fields, under the guidance of sucl organizations as the Department of Scien tific and Industrial Research in England Verein Deutscher Ingenieure in Germany the Sorbonne in France, and others. Ac cording to present plans, the group i scheduled to sail on May 14 from New Yorl on the S. S. "Champlain." The tou comes as the culmination of 3 highl successful educational tours made t industrial and university laboratories i the United States in 1930, 1931, and 1935 under the direction of Maurice Hollanc (A'23, M'30) director of the division o engineering and industrial research of NRC

Prizes for Papers on Arc Welding

The James F. Lincoln Arc Welding Foun dation, according to information releasec by that newly created organization, wil distribute $200,000 among the winners o 446 separate prizes for papers dealing witl arc welding as a primary process of manu facture, fabrication, or construction in 11 major divisions of industry in order t stimulate intensive study of the subject The principal prize winner will receive no less than $13,700. Other prizes range from $7,500 to $100, the latter sum to be awardec each of 178 contestants who receive nc other prize but whose papers are adjudgec worthy of honorable mention.

In order to assure equal competitive op portunity, similar prizes are offered in th 11 major divisions of industry covered b the contest. These divisions are: automo tive, aircraft, railroad, watercraft, struc tural, furniture and fixtures, commercia welding, containers, welderies, functiona machinery, and industrial machinery. Wid diversification of awards is effected by fur ther dividing each major industry into vari ous subclassifications; with entrants re quired to select in advance the particula

oclassification to which their papers will ate.

When accepted by the jury of awards as operly classified, each paper will be in mpetition, in its particular subclassifican, for 5 initial prizes established for that oup. These are worth, respectively, 00, $500, $300, $200, and $100. From ong these subclassification winners 4 pers will be selected in each major indus- to receive additional prizes of $3,000, 000, $1,000, and $800. Thus these semifinalists will be awarded a total of 1,800. In addition, the semifinal win-s in the various divisions will be consid-d as possible recipients of the 4 main zes. These range from $10,000 to $3,500, h the winner of the grand prize receiving less than $13,700 for his paper.

Contestants, it has been announced, must ve papers in duplicate on file with the sec-ary of the foundation at Cleveland, Ohio, later than June 1, 1938. Prospective rants should communicate promptly h A. F. Davis, box 5728, Cleveland, for nplete details of the rules and conditions vering awards.

Standards

oposed Standards for Transformers

The sectional committee on transformers rking under the rules of procedure of the erican Standards Association has prac-lly completed its work in drawing up new set of standards for transformers, ulators, and other induction apparatus, ording to V. M. Montsinger, chairman the AIEE standards committee. These l be submitted to the sectional committee final approval in the near future.

These new standards, having as their is the present AIEE Standards No. 13, e incorporated in them not only the st practices but a considerable amount material from standards of the National ctrical Manufacturers Association. In appendixes have been placed a new of guides for the operation of trans-ners, a development of the AIEE recom-ndations on operation giving for the time permissible short-time overloads both power and distribution trans-ners. Also, an enlarged and revised code for transformers will be included n appendix.

t is planned after approval by the com-tee and the ASA to publish these as erican Tentative Standards for dis-ution to all interested societies for nments and suggestions for improve-nt before they are published as final erican Standards. It is expected that tentative drafts will be published within next few months.

t Code for Synchronous Machines. An nsive revision of the "Preliminary ort on a Proposed Test Code for Synchronous Machines" came up for general discussion at one of the informal conferences held during the recent winter convention of the Institute. Copies are now available in pamphlet form and can be obtained gratis by writing H. E. Farrer, secretary AIEE standards committee, 33 West 39th Street, New York, N. Y. The AIEE committee on electrical machinery under whose auspices all of the test codes on rotating machinery are being developed hopes, as a result of the open discussion of the report at the conference and possible criticisms which may develop through wide circulation of the printed pamphlet, to be able shortly to make available a final approved synchronous code satisfactory to all.

Test Code for D-C Machines. At the same informal conference at which the synchronous code referred to in the preceding paragraph was discussed, there was also presented a preliminary draft of a proposed "Test Code for D-C Machines." This has not yet reached the stage where it is ready for general distribution in printed pamphlet form as several important points are still open to argument. As soon as these are cleared up, publication will take place and copies will then be available to all for further criticism and suggestion.

Test Code for Induction Machines. The second step toward the development of a finally approved "Test Code for Induction Machines" was also taken at the winter convention conference to which previous reference has been made. This code first appeared in preliminary report form in December 1934. When the revised and approved code will become available is impossible to predict just at present, but it is expected that the electrical machinery committee will shortly be in a position to ask the approval of the standards committee of this induction machinery code.

Test Code for Sound Level Measurements. At the meeting on January 25, 1937, of the standards committee a report was received from P. L. Alger, chairman of its subcommittee on sound, advising that the subcommittee is preparing a "Test Code for Sound Level Measurements on Apparatus." It is intended for use as a guide in the measurement of sound levels and the investigation of the various elements that contribute to the total noise produced. The standards committee agreed to issue the code in pamphlet form when completed.

Rotation, Connections, and Terminal Markings for Electric Power Apparatus. A new American Standard for "Rotation, Connections, and Terminal Markings for Electric Power Apparatus" has just been issued in pamphlet form by the National Electrical Manufacturers Association, the sponsor organization. This project, known as *C*–6, has been going forward in a sectional committee working under the rules of procedure of the American Standards Association, the Institute being one of the organizations represented on the committee. The first edition of the standard received approval in 1925 and this revision was approved by American Standards Association in June 1936. Copies of the standard may be obtained at 90 cents each by addressing National Electrical Manufacturers Association, 155 East 44th Street, New York, N. Y.

Revised Dry Cell Standards. A revision of "Specifications for Dry Cells and Batteries," approved as an American Standard in 1930 and issued as "Bureau of Standards Circular 390," has just been approved by the American Standards Association. The new edition will be issued shortly by the sponsor, the Bureau of Standards, under the official designation of *C* 18–1937.

Proposed Revision of National Electrical Safety Code. The National Bureau of Standards, the sponsor under ASA procedure for the sectional committee on national electrical safety code, is taking the preliminary steps calling for a reorganization of the committee which when completed will consider a revision of the safety code as approved by ASA in 1927.

Proposal for International Standardization of Photometric Units. The National Bureau of Standards will propose in the near future the international adoption of fundamental photometric units which, if adopted, will involve a slight change in the units in use in this country. Essentially the proposal will be as follows: That the primary standard of light shall be the black body radiator operated at the temperature of solidification of pure platinum; that the brightness of the primary standard shall be taken as 60 candles per square centimeter, thus fixing the magnitude of the unit of intensity, the candle, for the color of light given by the primary standard; that standards for light of colors different from that of the primary standard shall be established by applying the "visibility factors" which have been adopted by the Illuminating Engineering Society, the American Standards Association, the International Commission on Illumination, and the International Committee on Heights and Measures. The Institute will appoint a representative on the subcommittee which will consider the full proposal and its effect upon American practice.

Power and Rate Terms. There has just been issued by the Federal Power Commission, Electric Rate Survey, a "Glossary of Important Power and Rate Terms, Abbreviations, and Units of Measurement." This pamphlet, which should be of considerable interest to those in the power generation field, has as its purpose the development of a uniform terminology for the reports and correspondence of the commission. Quite a number of the definitions of electrotechnical terms appearing in the glossary have been developed in co-operation with the interested subcommittees of the sectional committee on electrical definitions, of which the Institute is sponsor. Copies of the glossary may be obtained from the Superintendent of Documents, Washington, D. C., at 5 cents each.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy, to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Effective Resistance of Synchronous Machines

To the Editor:

It is well known that the effective resistance of a synchronous machine is greater than the d-c resistance due to eddy current and hysteresis losses caused by the armature leakage flux, proximity effects due to armature current, and additional losses due to the distortion of flux under load. An approximate value of these losses may be obtained from the short-circuit loss and the armature I^2R_{dc} loss.[1] This method gives values which are too low, since under dead short circuit, the flux in the machine is small. Robertson[2] gives a complete discussion of the subject, and his figures 1 and 2 show the errors to be expected. In computing the machine efficiency, it is customary to make an approximate correction in which the core loss is taken corresponding to the internal voltage.[1] It is the writer's opinion that more accurate results will be obtained using the effective resistance determined from the V-curve test,[2] and an improved method which includes the increase in core loss under load will be described in the paragraphs following.

The effective armature resistance is defined as the ratio of the power per phase consumed in the armature windings to the square of the current. The power (using the per unit system throughout) consumed with the motor running light and all shaft load disconnected, may be expressed:

$$P = I^2R + b$$

where

P = power consumed with machine running light

I = armature current

b = sum of constant losses (windage, friction, and iron)

R = effective armature resistance

With the machine terminal voltage held constant, values of total power and armature current are obtained by varying the field current. The curves of figure 1 of this letter show typical results obtained from a 3-phase 6-pole 15-kva 1,200-rpm 220-volt 39.4-ampere generator. The power was measured by the 2-wattmeter method.

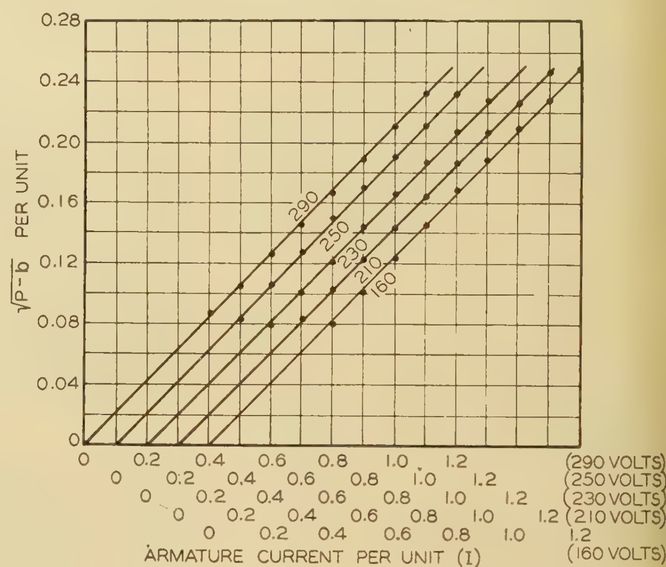


Fig. 2. Determination of effective armature resistance

Terminal voltages held constant at values shown on curves

Subscripts will be used to refer to 2 widely separated points on the same power-current curve.

$$P_1 = I_1^2R + b \qquad P_2 = I_2^2R +$$

Solving for the constant losses

$$b = (I_1^2P_2 - I_2^2P_1)/(I_1^2 - I_2^2)$$

Transposing the original equation and taking the square root gives

$$\sqrt{P - b} = I\sqrt{R}$$

Values of $\sqrt{P - b}$ and I were plotted to give straight lines passing through the origin; see figure 2. For a given terminal voltage, the effective resistance equals the square of the slope of the line.

The method is simple and effective, as the constant losses are evaluated without difficulty. If the value of b is larger than the correct value, the curve will depart from a straight line and be concave downward, while if it is smaller than the correct value the converse will be true. The value b can be conveniently corrected by plotting widely separated points on the $\sqrt{P -}$ versus I curve. A straight line is drawn connecting the larger value with the origin. If the second point does not fall on the line, b can be changed slightly to make it so.

The method assumes that the effective resistance is constant and independent of current. The correctness of this assumption is verified by an examination of the drift of points from the $\sqrt{P - b}$ versus

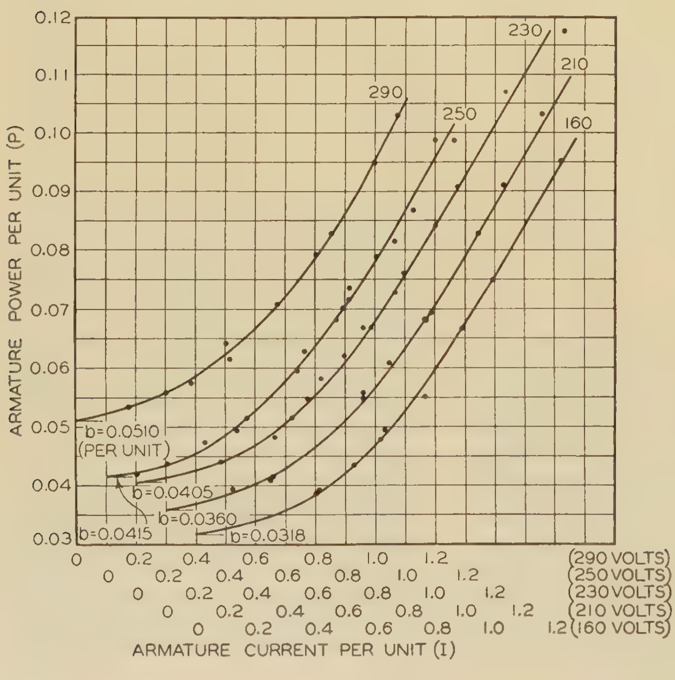


Fig. 1. Determination of effective armature resistance

Terminal voltages held constant at values shown on curves

re. The results for 5 independent tests various terminal voltages indicate that e is no appreciable variation with age. The effective resistance was taken he average value, $R = 0.044$.
he ohmic resistance of the armature ding was determined by the d-c volt-neter method. The average resistance $R_{dc} = 0.035$. It is apparent that the y losses may be expressed as a resistance. it is desired to determine the machine ormance at temperatures different from , the corrected effective resistance is id as follows:

$$= R_{t0} - R_{dct0} \quad \text{and} \quad R_{t1} = R_s + R_{dct1}$$

hich

= effective resistance at temperature t_0
= effective resistance at temperature t_1
, = ohmic resistance at temperature $t0$
= ohmic resistance at temperature $t1$
= stray losses expressed as a resistance.

using this method, the core loss should taken corresponding to the terminal age, since the variation in core loss is n into account in the effective resistance. s believed that this method of deter-ing the effective resistance is more rate than the conventional procedure etermining the d-c resistance and the y load losses from a short circuit test, e the additional losses due to flux dis-ion, and the increase in core loss under , are taken into account. The advan-s of the method are that the effective tance may be considered constant for t practical cases, and may be inserted ctly in the vector diagram, hence sim-ing the analysis.

ERENCES

MERICAN STANDARDS FOR ROTATING ELEC-L MACHINERY. Approved by American lards Association, January 6, 1936.

ESTS ON ARMATURE RESISTANCE OF SYN-NOUS MACHINES, B. L. Robertson. ELEC-L ENGINEERING (AIEE TRANSACTIONS), vol-54, July 1935, pages 705–09.

Very truly yours,
CHARLES F. DALZIEL (A'33)
Instructor in Electrical Engineering, University of California, Berkeley

A Formula for 2-Winding ransformer Regulation

he Editor:

hould like to submit the following as a vation for the ASA equation for regulation of a 2-winding transformer. The notation used is the same as that used by J. E. Clem, page 466 of the May 1936 issue of ELECTRICAL ENGINEERING, in the paper "An Exact Formula for Transformer Regulation."

From figure 1 of this letter,

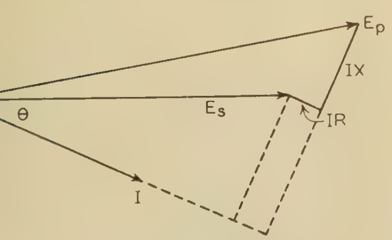


Fig. 1. Vector diagram

$$E_p = \sqrt{(E_s \cos\theta + IR)^2 + (E_s \sin\theta + IX)^2}$$

Dividing each side of the equation by E_s gives

$$\frac{E_p}{E_s} = \sqrt{(m + r)^2 + (n + x)^2}$$

where $r = IR/E_s$ and $x = IX/E_s$

Per cent regulation =

$$\left[\frac{E_p - E_s}{E_s}\right] \times 100 = \left[\frac{E_p}{E_s} - 1\right] \times 100$$

$$= \left[\sqrt{(m + r)^2 + (n + x)^2} - 1\right] \times 100$$

Very truly yours,
JOHN D. SCARBOROUGH (Enrolled Student)
Michigan College of Mining and Technology, Houghton

Personal Items

W. H. Harrison Nominated for Presidency

WILLIAM HENRY HARRISON (A'20, M'30, F'31, vice-president) assistant vice-president, department of operation and engineering, American Telephone and Telegraph Company, New York, N. Y., has been nominated for the presidency of the AIEE for the 1937–38 term. Mr. Harrison was born June 11, 1892, at Brooklyn, N. Y., and was graduated in industrial electrical engineering at Pratt Institute in 1915. He entered the employ of the New York Telephone Company in 1909, where his work until 1915 included apparatus inspection, assembling, and wiring. From 1915 to 1919 he was engaged in telephone circuit design in the engineering department of the Western Electric Company, and in 1919 he became a member of the engineering staff of the American Telephone and Telegraph Company. In 1924 Mr. Harrison was made equipment and building engineer with general supervision of the engineering of the subscribers station and central office plant of the Bell Telephone System, and in 1929 he became plant engineer, with broadened responsibilities including general direction of the engineering, design, and layout of all departments of the Bell System plant, including system relations with other wire-using utilities. In 1933 Mr. Harrison was elected vice-president in charge of operations of The Bell Telephone Company of Pennsylvania and The Diamond State Telephone Company of Delaware, with headquarters in Philadelphia, Pa. He was appointed assistant vice-president in the department of operation and engineering in 1937. Mr. Harrison has a long record of active service in the Institute; he is at present vice-president representing the AIEE Middle Eastern District (number 2) and a member of the executive committee (1936–37) and committees on legislation affecting the engineering profession, 1932–37; Edison Medal, 1935–37; and Lamme Medal, 1935–38. In addition, he is a member of the special committee to consider Associate dues and related matters and the committee on revision of Section territories, and has been a member of the following technical committees: communication, 1935–36; technical program, 1929–36 (chairman 1931–33); co-ordination of Institute activities, 1931–33; publication, 1931–33; award of Institute prizes, 1931–34 (chairman 1931–33); and popular science award, 1931–34. Mr. Harrison also was a member of the AIEE national nominating committee in 1935, and was an AIEE representative on the Alfred Noble Prize committee of the American Society of Civil Engineers (1932–34) and on the American committee on marking of obstructions to air navigation during 1932–33.

Vice-Presidential Nominees are Jollyman, McClellan, Mc Henry, Stein, Wood

JOSIAH PICKARD JOLLYMAN (A'05, M'25, F'30) chief of the division of hydroelectric and transmission engineering, Pacific Gas and Electric Company, San Francisco, Calif., has been nominated to serve the Institute as vice-president representing the Pacific District (number 8). Mr. Jollyman was born at Santa Barbara, Calif., October 29, 1879, and received the degree of bachelor of arts in electrical engineering at Stanford University in 1903. From 1903 to 1909 he was employed by the California Gas and Electric Corporation as an electrician and as superintendent of electrical construction. In 1909 he became electrical engineer for the Great Western Power Company of California, where he remained until he joined the engineering staff of the Pacific Gas and Electric Company in 1911. Since 1920 Mr. Jollyman has been chief of the division of hydroelectric and transmission engineering, in which position he has had charge of the electrical and mechanical design of 11 hydroelectric plants and the electrical design of several transmission lines and substations of large capacity. Mr. Jollyman has presented before the Institute several papers on transmission engineering subjects and has been a member of the committees on power stations (now power generation), 1923–24; and power transmission and distribution, 1915–17, 1923–29, 1930–37. He has been active in the affairs of the San Francisco Section, and was chairman of that Section during 1920–21.

Leslie Newman McClellan (A'14, M'26) chief electrical engineer, United States Bureau of Reclamation, Denver, Colo., has been nominated to serve the Institute as vice-president representing the North Central District (number 6). He was born at Middletown, Ohio, March 27, 1888, and received the degree of bachelor of science in electrical engineering in 1911 from the University of Southern California. He was then employed by the United States Reclamation Service at Phoenix, Ariz., on the Salt River project as electrical assistant, 1911–13; junior engineer, 1913–14; assistant engineer, 1914–15; and engineer in responsible charge of construction and operation of the power system, 1915–17. During 1917–18 he served overseas as a lieutenant in the United States Army Engineer Corps, upon his return becoming electrical engineer in the office of the chief engineer of the Reclamation Service at Denver, where he was engaged in the design of power plants, substations, and transmission lines. Mr. McClellan was employed by the Southern California Edison Company as engineer in the transmission department during 1923–24. Since 1924 he has held his present position as chief electrical engineer for the Bureau of Reclamation at Denver, where he has responsible charge of design, construction, and operation of power and pumping plants, substations, and transmission lines on the various reclamation projects of the Federal Government. Mr. McClellan is the author of papers on the Boulder Dam project published by the Institute, and was a member of the power transmission and distribution committee 1933–36.

Morris James Mc Henry (A'11, M'20) district manager of the Canadian General Electric Company, Toronto, Ont., Canada, has been nominated to serve the Institute as vice-president representing the Canada District (number 10). Mr. Mc Henry was born at Catasauqua, Pa., August 7, 1888, and received the degree of bachelor of science in electrical engineering at McGill University in 1910. Following his graduation, and until 1912, he was employed by Smith, Kerry, and Chase, consulting engineers, Toronto, in power station design and field engineering. In 1912 he was employed by the Canadian General Electric Company as sales engineer in Toronto, and in 1916 became assistant manager of apparatus sales in the Toronto district. In 1918 Mr. Mc Henry accepted a position as manager and secretary-treasurer of the Walkerville Hydro-Electric System, and remained as chief executive of that system until 1924. In that year he became sales manager of the Ferranti Electric Company, Ltd., which position he relinquished in 1926 to become manager of the United States sales department of the Canadian General Electric Company. In 1930 he was appointed district manager for Ontario. Mr. Mc Henry has served the Institute as a member of the committee on industrial and domestic power during 1921–22, and has been active in local Institute affairs. In the Toronto Section he has served as director (1924) and chairman (1935–36), and as chairman of the Section committees on membership (1925) and papers (1926). Mr. Mc Henry is a past-president of the Association of Municipal Electric Utilities of Ontario and a member of the Association of Professional Engineers of Ontario, having served as a member of the board of governors of that organization during 1924 and 1925. He is president of the Electric Club of Toronto and president of the Electric Service League of Toronto.

Irving Melville Stein (A'18, M'27) director of research for Leeds and Northrup Company, Philadelphia, Pa., has been nominated to serve the Institute as vice-president representing the Middle Eastern District (number 2). Mr. Stein was born at Long Branch, N. J., March 20, 1894, and obtained his technical education from the New York Edison evening technical school, Columbia University extension course, and Fort Wayne Correspondence School. He was employed in the meter department of the New York (N. Y.) Edison Company in 1911, and the following year was transferred to the standardizing laboratory. During 1913 he was in charge of the rehabilitation work on instruments damaged in the flood at Dayton, Ohio, then returned to the test department of the Edison company. In 1916 he was made assistant foreman of the standardizing laboratory, and the following year was made foreman. During this time he was also engaged in work on protective relays. During 1918 he was senior inspector in the eastern department of the U.S. Signal Corps, and also worked as personal assistant to Thomas A. Edison in the development of submarine and airplane locating devices. He was engaged by the Leeds and Northrup Company as sales engineer in 1919, and 2 years later was given charge of general division sales. In 1924 he was made assistant sales manager and in 1927 was given charge of development, engineering, production, publicity, and sales of combustion control apparatus. He is now director of research and a member of the executive committee of the company. Mr. Stein is the author of numerous technical articles. He has been a member of the Institute's publication committee since 1934 (chairman 1936–37), of the committee on coordination of Institute activities since 1933, and of the Sections committee since 1929, serving as chairman 1933–36. He served on the membership committee 1926–27 and 1931–33, and for 1936–37 has been appointed a member of the committees on technical program and award of Institute prizes. Among other organizations of which Mr. Stein is a member may be included the American Physical Society, American Chemical Society, American Electrochemical Society, Illuminating Engineering Society, Franklin Institute, and American Society for Testing Materials.

Edwin Dow Wood (A'21, M'26) general superintendent of the Louisville Gas & Electric Company, Louisville, Ky., has been nominated to serve the Institute as vice-president representing the Southern District (number 4). Mr. Wood was born at Montevideo, Uruguay, April 17, 1878, and attended high school at Callao, Peru. In 1903 he received the degree of bachelor of science at De Pauw University, Greencastle, Ind., and entered the employ of the Union Traction Company of Indiana. During the next year he was employed by the Pope-Waverly Electric Company of Indianapolis, Ind., and the General Electric Company at Schenectady, N. Y., for short periods before he joined the Empresa Electrica Santa Rosa at Lima, Peru, later the Empresas Electricas Asociadas. He became assistant chief engineer in charge of power plants for this company, and was acting chief engineer when he resigned in 1909 to become construction department foreman for the General Electric Company at Schenectady, N. Y. In the following year he was transferred to the engineering department in the Cincinnati, Ohio, district, where he was engaged in general power house and substation engineering work. Mr. Wood accepted the position of electrical operating engineer with the Louisville Gas & Electric Company in 1915, and was electrical engineer from 1926 to 1932, being appointed general superintendent in the latter year. In 1936 he was made a director of the company. Mr. Wood is a past-president of the Engineers and Architects Club of Louisville and a past-chairman of the Louisville Section, and until its dissolution was a member of the electrical apparatus committee of the former National Electric Light Association. He is co-author of an Institute paper published in 1931.

Bush, Beardsley, Lane Nominated for Institute Directorships

Vannevar Bush (A'15, M'19, F'24, Lamme Medalist '35) vice-president of Massachusetts Institute of Technology and dean of the school of engineering, Cambridge, Mass., has been nominated to serve the AIEE as a member of its board of directors. Doctor Bush was born at Everett, Mass., March 11, 1890. In 1913 he was graduated from Tufts College, and in 1916 was awarded the degree of doctor of engigineering from Massachusetts Institute of Technology and Harvard University. In 1932 he received the honorary degree of doctor of science from Tufts College, and he is now a member of the board of trustees of that college. Following graduation from Tufts College he entered the testing department of the General Electric Company, and the next year was an instructor in mathematics at Tufts College. In 1915 he engaged in graduate study at M.I.T., and the following year returned to Tufts as assistant professor of electrical engineering. During 1917–18 Doctor Bush carried on research work in submarine detection for the United States Navy; then until 1923 was associate professor of electric power transmission at M.I.T. From 1917 to 1922 he was also consulting engineer for the American Radio and Research Corporation. In 1923 he was appointed professor of electric power transmission, holding this title until appointed to his present position in 1932. Doctor Bush long has been interested in the design of analyzing instruments and is internationally known for his achievements in this field. For one development he was awarded the Levy Medal of the Franklin Institute in 1928, and he received the AIEE Lamme Medal for 1935. Doctor Bush is a director

f the Spencer Thermostat Company and of Raytheon, Inc., and is a member of the orporation of Massachusetts Institute of Technology. He is the author of many echnical articles and of "Operational Cir-uit Analysis," and, jointly with W. H. Timbie (A'10, F'24), of "Principles of Elec-rical Engineering." The Institute com-nittees on which he has served include re-earch (1924–30); electrophysics (1924–33, hairman 1931–33); power transmission nd distribution (1925–27, 1928–29); edu-ation (1928–29); and technical program 1929–33). He is now a member of the Edison Medal and Lamme Medal commit-ees, and representative on the division of ngineering and industrial research of Na-ional Research Council. Doctor Bush is a ellow of the American Academy of Arts and Sciences and American Physical Society, nd a member of the Society for the Pro-notion of Engineering Education, National Academy of Sciences, Phi Beta Kappa, Alpha Tau Omega, Sigma Xi, and Tau Beta Pi.

Clifford Ray Beardsley (A'08, M'20, F'30) superintendent of distribution, Brook-yn Edison Company, Brooklyn, N. Y., as been nominated to serve the Institute as a member of its board of directors. He was born at Bridgeport, Conn., December 19, 1885, and attended the Sheffield Scientific School of Yale University, from which he eceived the degree of bachelor of philosophy n electrical engineering in 1905. He then ntered the testing department of the Gen-ral Electric Company at Schenectady, N. Y., and subsequently was assigned to the ffices at New York, N. Y., and New Haven, Conn. In 1911 he became sales agent for he United Illuminating Company at Bridge-ort, where he had charge of sales, construc-ion, and installation of factory electrifica-ions. Seven years later he accepted the osition of electrical engineer with Fred T. Ley & Company, Springfield, Mass., in which position he had charge of design and nstallation of power station and industrial lectrical work, being concerned mostly with hydroelectric and steam plants and ransmission lines. Mr. Beardsley ac-epted in 1923 the position with the Brook-yn Edison Company of electrical construc-ion engineer in charge of inside-plant elec-rical construction in power stations, sub-tations, and consumer vaults. In 1932 he was appointed assistant to the superintend-nt of distribution, and recently was ad-anced to the position of superintendent of istribution. During 1928–30 Mr. Beards-ey was chairman of the accident prevention ommittee of the former National Electric Light Association, and he has served as hairman of the committees for the 1936 nd 1937 winter conventions of the Insti-ute. He has written numerous articles on he relation of engineering to safety.

Francis Howard Lane (M'23) manager f the engineering division of the Public Utility Engineering and Service Corpora-on, Chicago, Ill., has been nominated to erve the Institute as a member of its board f directors. He was born at St. Louis, Mo., une 7, 1882, and studied electrical engineer-g at Lewis Institute, Chicago, Ill., from which he received the degree of mechanical engineer in 1904. He then entered the employ of H. M. Byllesby and Company as draftsman, and subsequently was engaged in preliminary investigations of projects, and construction. From 1910 to 1915 he was engaged in general investigations and appraisals of public-utility properties, and during 1915–17 was manager of the department of examinations and reports. Mr. Lane was made manager of engineering and construction of Byllesby Engineering and Management Corporation in 1917, and held this position continuously until the formation of the successor company, Public Utility Engineering and Management Corporation, in 1936, with which he assumed a similar position. He is a member of The American Society of Mechanical Engineers and the Western Society of Engineers.

W. I. Slichter Renominated as Institute Treasurer

Walter Irvine Slichter (A'00, M'03, F'12, national treasurer, member for life) professor and head of the department of electrical engineering at Columbia University, New York, N. Y., has been nominated to succeed himself as treasurer of the Institute. Professor Slichter was born at St. Paul, Minnesota, May 7, 1873, and was graduated at Columbia University in 1896 with the degree of electrical engineer. He entered the employ of the General Electric Company as a student in July 1896, and the following year was transferred to the office of Doctor C. P. Steinmetz, where he was engaged for a year in carrying on experimental work, tests, and calculations on various subjects. During the following 2 years, he was engaged in designing induction motors, alternators, rotary converters, transformers, and special experimental apparatus. For a number of years thereafter he devoted most of his time to the design of electrical machinery and, more particularly, the equipment of electric railways. In 1910 he was appointed professor of electrical engineering and head of that department at Columbia University, which position he still fills. During the war he was civilian director of the Air Service school for radio officers at Columbia University. Since 1914, Professor Slichter has devoted considerable time to instruction in electrical engineering to naval officers of the post-graduate school of the United States Navy. National treasurer since 1930, he was a member of the board of directors of the Institute from 1918 to 1922 and vice-president from 1922 and 1924, and served on the following committees: board's committee on technical activities, 1918–20; board of examiners, 1915–18 and 1924–28; co-ordination of Institute activities, 1920–24 and 1925–27; editing (later publication) 1914–21; education, 1916–20; executive, 1919–24; meetings and papers (now technical program) 1917–24; industrial and domestic power (now general power applications) 1922–23; finance, 1923–24; standards, 1923–26; legislation affecting the engineering profession, 1931–36 (chairman 1933–35); Iwadare foundation, 1931–33; and special committee on model registration law, 1933–34. He was also Institute representative on the United States National Committee of the International Electrotechnical Commission, 1928–32. Professor Slichter is now serving as chairman of the committee on Columbia University scholarships, of which he has been a member since 1922 and chairman since 1925, and as a member of the committees on constitution and by-laws (1925–28 and 1930 to the present; chairman 1925–27), Edison Medal (1918–22 and 1930 to the present), and electrical machinery (1934 to the present). In addition, he has been a representative on the library board of United Engineering Trustees, Inc., since 1915, Engineering Foundation board since 1930, engineering societies monographs committee since 1930, and advisory board of the National Bureau of Engineering Registration since 1933. Professor Slichter is the author of many articles on technical subjects, and has presented several papers and discussions before the Institute. He is a member of The American Society of Mechanical Engineers, Society for the Promotion of Engineering Education, and other organizations.

Frank Conrad to Receive Lamme Medal

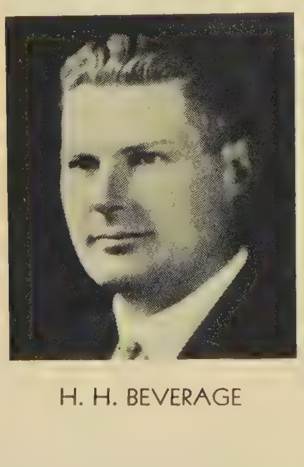
Frank Conrad (A'02, Edison Medalist '30) assistant chief engineer of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., has been awarded the Lamme Medal of the AIEE for 1936 "for his pioneering and basic developments in the fields of electric metering and protective systems." Doctor Conrad was

FRANK CONRAD

born at Pittsburgh, Pa., May 4, 1874, and joined the Westinghouse organization in 1890. In a short time he was transferred to the experimental and testing department, and in 1897 designed the so-called round type of watt-hour meter, which was smaller and more efficient than the previous square types. He then started the systematic redesign of all meters and instruments, which led to improvements in efficiency and the development of new types, among which were the relay-operated recording meter, power factor meter, electrostatic voltmeter, and ground detector. In 1904 Doctor Conrad was appointed general engineer, and for many years served as assistant to the vice-president in charge of engineering. He was appointed assistant chief engineer in 1921. About 1910 Doctor Conrad started the development of a complete elec-

trical system for automobiles, including in his designs voltage-regulated generators such as have come into universal use in the automobile industry in 1937. In 1912 he began investigations into radio telegraphy and telephony, designing and building radio transmitting and receiving equipment. Problems of power distribution for a-c railway systems also engaged his attention at this time. During the World War he aided in the production of telephone and telegraph equipment for the United States Army and Navy, and also designed grenades and grenade-throwing devices. Following the war he sent programs over the air from radio transmitters, and the equipment used by KDKA when that station began broadcasting in 1920 was designed by him. His investigations led to improved apparatus, and to a study of the short-wave field in which he sensed new possibilities. Other work in which he has been engaged includes units for household refrigerating purposes and electric clocks. Doctor Conrad is well-informed in biology, astronomy, and botany. In 1928 he was given the honorary degree of doctor of science by the University of Pittsburgh. Other awards he has received are the Morris Liebmann prize of the Institute of Radio Engineers in 1925, the Edison Medal of the AIEE in 1930, and the John Scott Medal of the City of Philadelphia in 1933. He is a fellow of the Institute of Radio Engineers and a member of the Society of Automotive Engineers and the American Association for the Advancement of Science, and holds the rank of lieutenant commander in the United States Naval Reserve.

H. H. Beverage (A'23, M'34) chief research engineer, R.C.A. Communications, Inc., New York, N. Y., recently was elected president of the Institute of Radio Engineers for the year 1937. Mr. Beverage was born October 14, 1893, at North Haven, Me., and was graduated from the University of Maine in 1915 with the degree of bachelor of science in electrical engineering. Upon graduation he was engaged by the General Electric Company, Schenectady, N. Y., as a test engineer, but in 1916 was transferred to the radio laboratories of that company as assistant to Doctor E. F. W. Alexanderson (A'04, F'20). In 1920 Mr. Beverage accepted a position with the Radio Corporation of America, where he was placed in charge of radio research on communication equipment, and continued there until 1929, when he was transferred to R.C.A. Communications, Inc., as chief communications engineer. He has been chief research engineer since 1932. Mr. Beverage has distinguished himself in his research on aperiodic directive receiving antenna systems and receiving systems for reducing the effects of fading at high frequencies. He is the holder of several patents on communication devices and systems, and in 1923 was awarded the Morris Liebmann Memorial Prize of the Institute of Radio Engineers for his research work on directive antenna systems. He is author or co-author of many papers on communication subjects, including 2 papers presented before the Institute, and is at present a member of the Institute's committee on communication. Mr. Beverage is a fellow of the Radio Club of America.



H. H. BEVERAGE

J. H. Payne (A'12, M'32) formerly with the Westinghouse International Company, recently was appointed chief of the electrical division of the Bureau of Foreign and Domestic Commerce, United States Department of Commerce, Washington, D. C. Mr. Payne was born June 24, 1883, at Titusville, Pa., and was graduated from Armour Institute of Technology with the degree of bachelor of science in electrical engineering in 1905. Immediately following his graduation, he entered the employ of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., being engaged first in engineering and construction work and later in the sales department at New York, N. Y. From 1915 to 1919 Mr. Payne had charge of a division making sales to mining companies. In 1920 he was transferred to the Westinghouse International Company and placed in charge of the selection and appointment of all of that company's distributors; later, he was made manager of the company's department of Europe, in which capacity he was in charge of the company's business in Europe and the dependencies of European countries. In 1929 he was appointed manager of the power department, in charge of the company's sales of central station and distribution equipment in all countries except the United States and Canada. Mr. Payne's duties with the Westinghouse International Company required extensive traveling in the United States and in 31 foreign countries.

J. H. PAYNE

W. H. Lawrence (A'99, M'12, member for life) chief operating engineer, The New York, (N. Y.) Edison Company, Inc., has retired. Mr. Lawrence was born February 28, 1870, at Middletown, Ohio. He entered the electrical industry in 1886, being employed as an apprentice for the General Electric Company, Schenectady, N. Y. After one year with that company, he became associated with the Edison Manufacturing Company at New York and soon thereafter filled the position of assistant superintendent of construction in the western offices of that company at Cincinnati, Ohio. He continued to serve in that capacity after the consolidation of the Edison and Thomson-Houston companies with the Central Thomson-Houston Company, but in 1889 was transferred to the Edison Electric Illuminating Company of New York. That company has since become The New York Edison Company, Inc., and Mr. Lawrence had completed 47 years of continuous service with the company at the time of his retirement. He is the author of several articles on station operation, including one paper presented before the Institute. He served the Institute as a member of the committee on power generation during the period 1920–29. Mr. Lawrence is a member of The American Society of Mechanical Engineers.

L. E. Emerich (A'24) who has been district manager of technical division sales in the Chicago, Ill., offices of the Leeds & Northrup Company, has been transferred to the Philadelphia, Pa., offices of that company as assistant sales manager in the technical sales division. Mr. Emerich was born at Schuylkill Haven, Pa., in 1898, and received the degree of bachelor of science at Carnegie Institute. After serving briefly with the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., and the Public Service Electric and Gas Company, Newark, N. J., he entered the sales department of the Leeds & Northrup Company at Philadelphia in 1923 and since then has been associated with that company continuously.

D. G. Evans (A'20) assistant general manager of the Wisconsin Gas and Electric Company, Racine, has been appointed general manager. Mr. Evans was born at Larned, Kans., in 1887, and received the degree of bachelor of science in electrical engineering at the University of Illinois in 1917. Following a brief service as transformer test engineer for the Wagner Electrical Manufacturing Company, he entered the employ of the Wisconsin Gas and Electric Company as an engineer in 1919. His service with that company has been without interruption.

J. R. Read (A'04) who has been district manager for the Canadian Westinghouse Company, Ltd., at Vancouver, B. C., Can., has been appointed vice-president of the company with headquarters at Hamilton, Ont. Mr. Read was born October 24, 1879, in Virginia. His early electrical experience was gained with the Westinghouse Electric & Manufacturing Company at East Pittsburgh, Pa. In 1901 he was engaged as con-

lting electrician for various gold-dredging mpanies in California, and later he became ectrical engineer for the Northern Cali-rnia Power Company at Redding. His anadian experience began in 1904 with his gagement as district-office sales engineer r the Vancouver district office of the Cana-an Westinghouse Company. In 1908 he as appointed district manager, and since at time has been associated with many nportant projects.

G. G. Post (A'11, F'33, past vice-presi-ent) vice-president in charge of power, ilwaukee Electric Railway & Light Com-any, Milwaukee, Wis., has been appointed representative of the Institute upon the ommission of Washington Award to fill an nexpired term ending August 1, 1938. r. Post, who was a vice-president of the stitute 1934–36, has been a member of e Institute's committee on power genera-on since 1932, and has served on the com-ittees on power transmission and distribu-on (1922–26), protective devices (1934–), and Edison Medal (1935–36). He has so been active on technical committees of e Association of Edison Illuminating Com-anies and the Edison Electric Institute.

B. L. Goodlet (A'25, M'30) research en-neer for the Metropolitan-Vickers Elec-ical Company, Ltd., Manchester, Eng-nd, recently accepted an appointment as ofessor in the department of electrical igineering at the University of Capetown, outh Africa. Professor Goodlet, a gradu-e of the Imperial School (Petrograd, ussia) and the University of Sheffield England), has been associated with the etropolitan-Vickers company since 1922.

J. F. Lincoln (A'08, M'20) president of e Lincoln Electric Company, Cleveland, hio, was honored recently by the board of rectors of the company when a newly eated fund and foundation for welding search was named "The James F. Lincoln rc Welding Foundation" in recognition his pioneer work in promoting arc welding id perfecting and developing arc-welding uipment and electrodes. Mr. Lincoln has rved on several Institute committees, id was a manager 1920-24.

Nathan Cohn (A'29) for several years strict manager of technical division sales r the Pacific coast, Leeds & Northrup ompany, San Francisco, Calif., has been ansferred to the Chicago, Ill., offices of at company in a similar capacity. Mr. ohn is a native (1907) of Hartford, Conn., id an electrochemical engineering graduate Massachusetts Institute of Technology. e has been associated with the Leeds & orthrup Company in its sales departments ice his graduation.

C. V. Armstrong (A'36) sales engineer r Ingersoll-Rand Company, New York, . Y., has been transferred to the Chicago, ., offices of that company.

H. C. Brown (A'20) formerly employed the U.S. Engineers office, Huntington, . Va., now is with the engineering division, orld's Fair, Inc., New York, N. Y.

A. R. Wellwood (M'22, F'36) former director of the regional office of the Federal Power Commission, Atlanta, Ga., has been appointed supervising engineer and placed in charge of all Public Works Administration power projects in Nebraska. Mr. Wellwood has been identified with the Federal Power Commission since 1934, and formerly was director of the Commission's electric rate survey, with headquarters at Washington, D. C.

E. E. Dreese (M'25) chairman of the electrical engineering department, Ohio State University, Columbus, has been appointed a trustee of "The James F. Lincoln Arc Welding Foundation," created recently to aid welding research. Principal direction of the foundation's work will be given by him. He has been a member of the Institute's committees on education and electrophysics since 1935, and is a member of the committee on student Branches.

L. M. La Fever (A'26) formerly an electrical tester for the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., has been transferred to the New York, N. Y., offices of that company as a field service engineer.

S. B. Gaylord (A'36) who has been employed by the Western Public Service Company, Broken Bow, Nebr., recently accepted a position in the test engineering department of the General Electric Company, Schenectady, N. Y.

P. B. Wahlquist (M'29) formerly manager of the concessions department, Telefonaktiebolaget, L. M. Ericksson, Stockholm, Sweden, has accepted an appointment as general manager, Empresa de Telefonos Ericsson, Mexico City, Mexico.

I. T. Monseth (A'26) engineering representative, Westinghouse Electric & Manufacturing Company, Kansas City, Mo., has been transferred to the St. Louis, Mo., offices of that company.

H. A. Stanley (A'07, M'19) plant engineer of the Berkshire Fine Spinning Associates, Inc., Fall River, Mass., has been transferred to the Providence, R. I., offices of that company.

Obituary

Edward Barnard Meyer (A'05, M'13, F'27, past vice-president, past-president) chief engineer of the Public Service Electric and Gas Company, Newark, N. J., died January 31, 1937. Doctor Meyer was born October 22, 1882, at Newark. He received his technical education at the Newark Technical School, from which he was graduated in 1901; and at Pratt Institute, Brooklyn, N. Y., where he was graduated in the electrical engineering course in 1903; in 1936 he received the honorary degree of doctor of engineering from the Newark College of Engineering. Following his graduation from Pratt Institute in 1903, Doctor Meyer entered the employ of the Public Service Corporation of New Jersey as an engineering assistant, and remained with that organization and its subsidiary companies continuously until 1922. During that period he became, in 1906, field engineer in charge of underground conduit and cable system; in 1909, assistant engineer on special engineering reports, estimates, and construction work; in 1912, assistant to the chief engineer; and in 1919 assistant chief engineer. When the Public Service Production Company was formed in 1922, he was made its chief engineer. In 1929 Doctor Meyer was made a vice-president of the Public Service Production Company, and in 1930, on the occasion of the merger of that company with United Engineers and Constructors, Inc., he was appointed a vice-president of the latter corporation in the capacity of executive and engineering head of the Newark office. He was appointed chief engineer of the Public Service Electric and Gas Company in 1935. Doctor Meyer was liberal in contributing his energy and ability to the causes of the Institute; he was a director from 1928 to 1931, a vice-president during 1932–34, and president for the term 1935–36. In addition, he served on the following committees: executive, 1928–30, 1932–34, and 1935–37 (chairman 1935–36); constitution and by-laws, 1929–35 (chairman 1934–35); co-ordination of Institute activities, 1925–35 (chairman 1934–35); Edison Medal, 1927–29 and 1930–36; finance, 1927–31 and 1932–34 (chairman 1928–30, 1933–34); headquarters, 1928–30 and 1933–34; Lamme Medal, 1928–30; membership, 1924–25; award of Institute prizes, 1925–28 and 1931–34 (chairman 1925–27); publication, 1923–35 (chairman 1927–28, 1931–34); Sections, 1926–27; technical program 1918–29, 1932–34 (chairman 1925–27); transfers, 1932–35 (chairman 1932–33); power generation, 1928–32; code of principles of professional conduct, 1936–37; and power transmission and distribution, 1918–24 (chairman 1918–23). Doctor Meyer served also on the special committees on Institute policies, 1931–33; Associate dues and related matters, 1932–37; on revision of Section territories (1935–37); and biographies and talking motion pictures, 1930–33. He served as an Institute representative on the U.S. National Committee of the International Electrotechnical Commission, 1927 to 1930; the American Engineering Council, 1935–36; the Charles A. Coffin fellowship and research fund committee, 1935–36; and on the Engineering Societies monographs committee, 1930–35. He was a member of the John Fritz Medal board of award for the term 1935–39. Doctor Meyer's other technical activities included participation in the affairs of the American Standards Association, the former National Electric Light Association, The American Society of Mechanical Engineers. His numerous contributions to the technical press include a book, "Underground Transmission and Distribution."

Crandall Zachariah Rosencrans (M'36) assistant director of research, Leeds & Northrup Company, Philadelphia, Pa., died January 7, 1937. Mr. Rosencrans was born January 4, 1897, at Chicago, Ill. He received the degrees of bachelor of science in mechanical engineering (1919), master

of science in mechanical engineering (1921), and mechanical engineer (1929) at the University of Illinois, and at the time of his death had nearly completed the requirements for the degree of doctor of philosophy. Following his graduation in 1921, he was appointed to the staff of the University of Illinois Engineering Experiment Station, where he became engaged in independent research on the thermodynamics of gas and oil engines, the mechanism of explosions, and gas-engine testing. In 1926 Mr. Rosencrans accepted a position as research engineer with the Leeds & Northrup Company, and during the following 2 years was responsible for research and development work on electrical methods of gas analysis. From 1928 to 1934 he served as chief of the mechanical division and acting chief of the metallurgical division, and for one year (1928–29) as chief of the chemical division of that company's research department. He was appointed assistant director of research in 1934. Mr. Rosencrans was the holder of several patents on electrical and mechanical measuring devices, and was the author of many scientific papers and articles. He was a member of The American Society of Mechanical Engineers, American Chemical Society, Franklin Institute, Institute of Metals (British), American Society of Refrigerating Engineers, American Association for the Advancement of Science, Verein Deutscher Ingenieure (German), Sigma Xi, and Tau Beta Pi.

William David Gherky (A'95, M'96, F'13, member for life) president of the Railway Track-Work Company, Philadelphia, Pa., died January 17, 1937. Mr. Gherky was born January 7, 1868, at Portsmouth, Ohio. In 1886 and 1887 he was employed as a telegraph operator in railway and commercial service, and in 1888 was engaged by the Edison Electric Company and placed in charge of a 2,400-lamp plant and its associated underground system. At the end of that year he was transferred to the engineering department of the Edison United Manufacturing Company. He remained only briefly with the Edison companies, however, and after serving with the Field Engineering Company, New York, N. Y., accepted a position as engineer in charge of the underground system of the Philadelphia (Pa.) Traction Company in 1893. Later Mr. Gherky organized the Railway Track-Work Company and in 1917 formed the General Grinding Wheel Corporation, of which he was chairman of the board. He was a member of the American Association for the Advancement of Science.

John Wilbert Purcell (A'13) assistant engineer, Hydro-Electric Power Commission of Ontario, Toronto, died December 12, 1936. Mr. Purcell was born February 29, 1872, at Listowel, Ont., Canada. In 1890 he entered the electrical industry and worked in various manufacturing plants until 1893, when he became superintendent and chief inspector of the Detroit Electric Light and Power Company. He remained in that position until the company was sold in 1896. At that time he entered the employ of Hiram Walker and Sons, Walkerville, Ont., as superintendent of the light and power department. Mr. Purcell joined the staff of the Hydro-Electric Commission in 1912 as assistant engineer in the municipal engineering department, where his duties consisted of developing loads in urban municipalities and rural districts, and in the search for applications of electricity to agricultural uses. He was a member of the Association of Professional Engineers of Ontario, and formerly was an active member of the Canadian Electrical Association.

Fremont Wilson (A'88, M'88, F'12, member for life) retired consulting engineer, Albany, N. Y., died October 27, 1936, according to word just received at Institute headquarters. Mr. Wilson was born July 15, 1861, at New York, N. Y., and attended the College of the City of New York. In 1882 he was employed by the Western Union Telegraph Company, but in the following year became associated with the Kuth Electric Company. From 1884 to 1887 he was engaged by the Edison Electric Company, New York, in the development of electric illuminating equipment, and from 1887 until 1892 he was with the Sprague Electric Company. Mr. Wilson established his own consulting engineering offices in New York in 1892, continuing as consultant to many electrical manufacturers until his retirement in 1934. He was particularly interested in the safety features of electrical devices, and was for many years consulting electrical engineer to the New York City Bureau of Fire Underwriters.

John Clement Dolph (A'03, member for life) president and founder of the John C. Dolph Company, Newark, N. J., died February 5, 1937. Mr. Dolph was born September 28, 1864, at North East, Pa. He entered the electrical industry by accepting employment as an apprentice electrician with the Short Electric Railway Company, Cleveland, Ohio; later, he established his own business as a sales representative in electrical and street railway supplies, in New York, N. Y. In 1898 Mr. Dolph became manager of the insulating varnish department of the Sterling Varnish Company Pittsburgh, Pa., and in 1901 accepted a similar position with the Standard Varnish Company, New York. In 1910 he moved to Newark and established his own insulating varnish company under the name of the John C. Dolph Company. He was considered an authority on insulating varnish.

Membership

Recommended for Transfer

The board of examiners, at its meeting on February 17, 1937, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Curry, Walter A., assistant professor of electrical engineering, Columbia University, New York, N. Y.
Mapes, Leland R., chief engineer, Illinois Bell Telephone Company, Chicago, Ill.

2 to Grade of Fellow

To Grade of Member

Judson, W. G., electrical engineer, Ward Leonard Electric Company, Mount Vernon, N. Y.
Rathbun, H. V., transmission engineer, Kansas City Power and Light Company, Kansas City, Mo.
Reznicek, Josef, professor of electrical engineering, Technical University, Prague, Czechoslovakia.
Starr, F. M., central station engineering department, General Electric Company, Schenectady, N. Y.
Summerfield, S. C., assistant engineer, New Jersey Bell Telephone Company, Newark.
Trost, F. J., assistant division distribution engineer, Public Service Electric and Gas Company, Jersey City, N. J.

6 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before March 31, 1937 or May 31, 1937, if the applicant resides outside of the United States or Canada.

Abbott, L. J., Texas Power and Light Co., Decatur, Texas.
Aicher, L. C., Jr., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Ambrosio, B. F., 335 Linwood Street, Brooklyn, N. Y.
Anderson, R. E., Lonoke, Ark.
Angelopoulos, N. C., Engineers, United States Army, Fort DuPont, Del.
Askren, LeR., Frigidaire Corporation, Dayton, Ohio.
Bailey, C. W., Schlumberger Well Surveying Corporation, Tyler, Texas.
Barken, J., Powell and Power Engineers, Dallas, Texas.
Barbaro, A., 17 Batavia Place, Harrison, N. Y.
Barnard, R. B. (Member), U.S. Engineer's, 523 Pittock Building, Portland, Ore.
Barnes, D. P., Southern Utah Power Company, Cedar City, Utah.
Barr, J. M., Jr., 1515 Blanding Street, Columbia, S. C.
Bastedo, E. H., Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.
Beahm, E. M., Albuquerque Gas and Electric Company, Albuquerque, New Mexico.
Beamer, S., Fireman's Fund Idemnity Company, San Francisco, Calif.
Beasley, R. R., Denver and Rio Grande Western Railroad Company, Murray, Utah.
Belding, M. D., Westinghouse Electric & Manufacturing Company, Knoxville, Tenn.
Bellows, G., Jr., General Electric Company, Schenectady, N. Y.
Betzer, R. W., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Beveridge, A. B., General Electric Company, Schenectady, N. Y.
Bixler, C. H., Allis-Chalmers Manufacturing Company, Pittsburgh, Pa.
Black, K. H., United States Army, Fort Lawton, Seattle, Wash.
Blake, W. J., American Rolling Mills, Middletown, Ohio.
Blair, F. M., Y.M.C.A., Evansville, Ind.
Bobo, R. A., Phillips Petroleum Company, Oklahoma City, Okla.
Bodholt, I. F., Western Electric Company, Kearny, N. J.
Bodine, R. B., General Electric Company, Schenectady, N. Y.
Bowman, H. J., Consumers Power Company, Kalamazoo, Mich.
Brands, W. H., Buffalo General Electric Company, Buffalo, N. Y.
Brannin, R. S., Jr., West Texas Utilities Company, Abilene, Texas.
Bridges, J. M., New York Telephone Company, Brooklyn, N. Y.

ll, E. C., Emerson Electric Manufacturing Company, St. Louis, Mo.
nkerhoff, J. K., Allis-Chalmers Manufacturing Company, West Allis, Wis.
ck, H. A., Oklahoma Gas and Electric Company, Muskogee, Okla.
ndage, T. W., General Electric Company, Pittsfield, Mass.
mfiel, R. W., Tennessee Power Company, Chattanooga, Tenn.
ran, H. V., Jr., Bethlehem Steel Company, Sparrows Point, Md.
chanan, C. H., 431 Avenue D, Forest Hills, Wilkinsburg, Pa.
ck, L. L., New Jersey Bell Telephone Company, Newark, N. J.
dington, W. I., Westinghouse Electric & Manufacturing Company, Chicopee Falls, Mass.
ckeridge, R. M., Shallcross Controls, Inc., Milwaukee, Wis.
rr, L. S., Fibreboard Products, Inc., Stockton, Calif.
rkhardt, N. C., Cutler-Hammer, Inc., Milwaukee, Wis.
dwell, R. J., General Electric Company, Pittsfield, Mass.
mpbell, S. P., Coleman Lamp and Stove Company, Wichita, Kan.
mpani, L. M., United States Gauge Company, Sellersville, Pa.
rolan, J. G., 58 Holland Avenue, Floral Park, N. Y.
taldo, V. M., Sears Roebuck and Company, New York, N. Y.
twood, R. E., Kansas Power and Light Company, Hiawatha, Kan.
mielewicz, E. A., Acme Electric and Manufacturing Company, Cleveland, Ohio.
sell, R. F., General Electric Company, Erie, Pa.
rk, O., Continental Can Company, Oakland, Calif.
ne, R. F., Norton Company, Chippawa, Ont., Canada.
e, J. D., Schweitzer and Conrad, Chicago, Ill.
eman, O. K. (Member), American Gas and Electric Company, New York, N. Y.
ndren, J. M., Jr., Otis Elevator Company, New York, N. Y.
nverse, H. D., Fulton Sylphon Company, Knoxville, Tenn.
ok, W. L., General Fire Company, Providence, R. I.
rnelius, M. P., Officer's Reserve Corps, Fort Bliss, Texas.
ib, J. F., Stromberg Carlson Telephone Manufacturing Company, Rochester, N. Y.
oss, C. B., Narragansett Electric Company, Providence, R. I.
ta, J., Star Fuel Oil Company, Inc., Ridgefield Park, N. J.
an, D. E., Fibreboard Products, Inc., Antioch, Calif.
rtis, E. M., American Steel & Wire Company, Worcester, Mass.
hatowski, A. W., 7 Limerick Street, Gardner, Mass.
nford, F. E., General Electric Company, Erie, Pa.
niel, C. A., General Electric Company, Schenectady, N. Y.
nko, J. T., McKeesport Technical High, McKeesport, Pa.
sburg, A. van C., Baltimore and Ohio Railroad Company, Cincinnati, Ohio.
vid, T. H., Jr., General Electric Company, Fort Wayne, Ind.
vis, G. G., General Electric Company, Schenectady, N. Y.
vis, L. B., Chesapeake and Potomac Telephone Company, Washington, D. C.
wson, J. H., Sumter Machinery Company, Sumter, S. C.
Gaizo, C. L., Indiana Bell Telephone Company, Indianapolis, Ind.
mpsey, W. A., New England Power System, Lawrence, Mass.
kinson, W. H., 105 Haven Avenue, New York, N. Y.
hl, R. P., (Member) Park City Consolidated Mines Company, Park City, Utah.
lson, H. A., Southwestern Light and Power Company, Lawton, Okla.
nby, H. R., General Electric Company, Fort Wayne, Ind.
nahue, J., 266 Gifford Avenue, San Jose, Calif.
sey, J. S., Monroe Calculating Machine Company, Manchester, N. H.
ugherty, C. J., 2122 Cass Street, Fort Wayne, Ind.
ver, R. S., Fansteel Metallurgical Corporation, North Chicago, Ill.
per, H. K., Pacific Lumber Company, Scotia, Calif.
ker, K. E., Southern California Edison Company Ltd., Big Creek, Calif.
nlap, C. W., Jr.,5406 Red Oak Drive, Hollywood, Calif.
yer, J. J., Omega Gold Mines Ltd., Larder Lake, Ont., Canada.
er, G. S., Jr., Bell Telephone Laboratories, Inc., New York, N. Y.
ls, H. G., General Electric Company, Schenectady, N. Y.
s, E. P., 19 Curtis Place, Maplewood, N. J.
ler, W. G., Square D Company, Los Angeles, Calif.
nhut, W. F., Consolidated Edison Company of New York Inc., New York, N. Y.
s, E. R., Alabama Power Company, Birmingham, Ala.

Elmendorf, C. H., III, Bell Telephone Laboratories, Inc., New York, N. Y.
Ember, T., Electrical Products Inc., Baltimore, Md.
Eppes, J. B., Jr., Chesapeake and Potomac Telephone Company, Severna Park, Md.
Erwin, R. A., Department of Water & Power, Los Angeles, Calif.
Esayian, C. G., Philadelphia Storage Battery Company, Philadelphia, Pa.
Escher, H., Jr., General Electric Company, Bloomfield, N. J.
Evans, G. S., Westinghouse Electric & Manufacturing Company, Turtle Creek, Pa.
Evans, T. C., Jr., Federal Power Commission, Washington, D. C.
Eveland, E. H., New York Telephone Company, Brooklyn, N. Y.
Feeney, R. J., Kinnear Manufacturing Company, Columbus, Ohio.
Fenimore, R. A., Indiana Bell Telephone Company, Indianapolis, Ind.
Fenton, R. F., Jr., Box 296, Clarks, La.
Fingerle, W., Jr., Duro Test Corporation, New York, N. Y.
Fink, L. R., 1686 Scenic Avenue, Berkeley, Calif.
Fisher, C. A., E. I. du Pont de Nemours and Company, Buffalo, N. Y.
Fisher, W. C., 24 Benson Avenue, Westwood, N. J.
Flarsheim, E. S., Liebel Flarsheim Company, Cincinnati, Ohio.
Fleming, J. G., Cambridge Instrument Company Inc., Ossining, N. Y.
Forsberg, E., John Morrell and Company, Sioux Falls, S. D.
Fowler, R., Jr., New England Power Association, Providence, R. I.
Fox, J. P., Public Service Company of Northern Illinois, Evanston, Ill.
Frederick, W. R., International Business Machine Corporation, Endicott, N. Y.
Friede, H. A. (Member), Police Telegraph and Municipal Telephone System, Washington, D. C.
Friel, A. C., 500 Wolverine Building, Ann Arbor, Mich.
Fritschel, P. G., General Electric Company, Schenectady, N. Y.
Frolich, J. F., Port of New York Authority, New York, N. Y.
Fuge, H. B., Diehl Manufacturing Company, Elizabethport, N. J.
Gamble, G. L., Bell Telephone Laboratories, Inc., New York, N. Y.
Garlan, H., 233 East 12th Street, New York, N. Y.
Garlinghouse, L. E., Idaho Power Company, Twin Falls, Idaho.
Garner, H. J., Board of Fire Underwriters of the Pacific, San Francisco, Calif.
Garr, D. E., General Electric Company, Erie, Pa.
Gee, S. C., General Electric Company, Schenectady, N. Y.
Gibson, M. P., Gibson Dry Goods Company, Plattsburg, Mo.
Gil, F., Mex. Meridional de Fza., Miacatlan, Mor., Mexico.
Gilardi, A. J., 2552 Haste Street, Berkeley, Calif.
Gilbert, T. H., San Diego Consolidated Gas and Electric Company, San Diego, Calif.
Ginn, W. S., General Electric Company, Schenectady, N. Y.
Gitelson, S., Simplex Wire and Cable Company, Belmont, Mass.
Goudenkoff, A., Canadian Electrical Manufacturing Company Ltd., Vancouver, B. C., Canada.
Gould, J. P., Copperweld Steel Corporation, Chicago, Ill.
Grady, C. D., 215 No. 12 Boulevard, St. Louis, Mo.
Grange, L. N., Mountain States Telephone and Telegraph Company, Ogden, Utah.
Granvdal, N., American Chicle Company, Long Island City, N. Y.
Gray, J. B., Puget Sound Power and Light Co., Renton, Wash.
Gray, S. McK. (Member), Electrical Testing Laboratories, New York, N. Y.
Gregory, C. N , Jr., Philadelphia Storage Battery Company, Philadelphia, Pa.
Greulich, R. A., Pacific Telephone and Telegraph Company, Elko, Nev.
Grim, J. S., Jr. (Member), American Telephone and Telegraph Company, New York, N. Y.
Grimshaw, C. S., General Electric Company, Schenectady, N. Y.
Grossman, B., 475 Paulison Avenue, Passaic, N. J.
Groves, W. E., Radio Station KSL, Salt Lake City, Utah.
Guenzel, E. G., 326 Union State Bank Building, Omaha, Neb.
Haasch, D. E., Idaho Power Company, Weiser, Idaho.
Haeger, A. J., Guardian Electric Company, Chicago, Ill.
Halkins, W. B., Philco Radio and Television Company, Philadelphia, Pa.
Halpert, P., Aerovox Corporation, Brooklyn, N. Y.
Hammond, F. C., S. S. White Dental Manufacturing Company, Staten Island, N. Y.
Hammond, J. R., Indiana and Michigan Electric Company, South Bend, Ind.
Harley, P. C., Western Union Telegraph Company, New York, N. Y.
Harmon, A. G., 1043 Common Street, Lake Charles, La.
Harkness, J. A., Pacific Scientific Company, Los Angeles, Calif.
Happe, W. H., Jr., Consolidated Edison Company, New York, N. Y.
Harmer, W. R., Canadian General Electric Company Ltd., Toronto, Ont., Can.

Harris, P. R., Southwestern Gas and Electric Company, Texarkana, Ark.
Healey, D. S., Jr., General Electric Company, Schenectady, N. Y.
Heath, E. F., Brooklyn Edison Company, Inc., Brooklyn, New York.
Hecht, H. N., 529 Bainbridge Street, Philadelphia, Pa.
Helmuth, R. E., Sunbeam Electrical Manufacturing Company, Evansville, Ind.
Hill, R. A., Western Geophysical Company, Los Angeles, Calif.
Hill, V. F., General Electric Company, Providence, R. I.
Hill, J. J., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Hilton, O. B., Indiana Bell Telephone Company, Indianapolis, Ind.
Hoffman, F. O., Cutler-Hammer, Inc., Milwaukee, Wis.
Hollingsworth, L. M., 667 Ninth Avenue, San Francisco, Calif.
Hornfeck, A. J., General Electric Company, Schenectady, N. Y.
Horr, A. F., Electric Steam Sterilizing Company, New York, N. Y.
Hottenstein, J. M., Philco Radio and Television Company, Philadelphia, Pa.
Howe, L. McL., Saskatchewan Power Commission, Saskatoon, Sask., Canada.
Huck, A. J., Knapp-Monarch and Company, St. Louis, Mo.
Hullinger, O. M., Line Material Company, So. Milwaukee, Wis.
Hunkins, H. R., Western Electric Company, Kearny, N. J.
Hurd, C. T., Allis-Chalmers Manufacturing Company, Seattle, Wash.
Hyde, E. L., Carolina Power and Light Company, Raleigh, N. C.
Immel, R. B., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Jeffcock, H. W., 55 Chestnut Street, Cohoes, N. Y.
Jenkins, F. L., Jr., Duke Power Company, Spencer, N. C.
Johnson, C. R., United States Rubber Products Inc., New York, N. Y.
Johnson, E. F., 3427 Norton Street, Everett, Wash.
Johnson, H. C., Newton, Abbe and Company, Boston, Mass.
Johnson, W. J., Philadelphia Electric Company, Philadelphia, Pa.
Johnston, R. W., Commonwealth and Southern Corporation, Jackson, Mich.
Katz, R., Ohio University, Athens, Ohio.
Kaufmann, H. A., University of Cincinnati, Cincinnati, Ohio.
Kayle, A. W., Western Electric Company, Kearny, N. J.
Keim, D. Y., Hygrade Sylvania Corporation, Emporium, Pa.
Kennedy, R. V., 728 North 14th Street, Milwaukee, Wis.
Keranen, E. W., 202 1/2 Portage Street, Hibbing, Minn.
Kersey L. R., 2946 W. 35th Avenue, Vancouver, B. C., Canada.
Killen, R. B., Dayton Power and Light Company, Dayton, Ohio.
King, E. F., Pure Oil Company, Cincinnati, Ohio.
Kleiman, M., Thompson-Gibb Electric Welding Company, Lynn, Mass.
Klotz, L. J., Jr., Orlando Utilities Commission, Orlando, Fla.
Knightley, W. J., Southwestern Bell Telephone Company, Wichita, Kan.
Kooker, E. M., General Electric Company, Schenectady, N. Y.
Koontz, H. F., Public Service Company of Oklahoma, Vinita, Okla.
Krach, K. J., U.S. Army, 34th Infantry, Ft. George G. Mead, Md.
Kropf, V. J., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Kueck, E. F., Square D Company, Detroit, Mich.
Kuchner, M. H., Otis Elevator Company, New York, N. Y.
L'Allemand, C. C., General Electric Company, Schenectady, N. Y.
La Marsh, J. E., Stewart Warner Corporation, Chicago, Ill.
Lane, H. R., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Lee, R. R., Fairbanks, Morse and Company, Beloit, Wis.
Lebenbaum, P., Jr., General Electric Company, Schenectady, N. Y.
Lehrkind, A., Burgess Battery Company, Madison, Wis.
Leffell, W. O., University of Tennessee, Knoxville, Tenn.
LeMoire, J. A., Electrical Testing Laboratories, New York, N. Y.
Lewellen, W. K., New England Power Association Malden, Mass.
Lewis, J. E., Minneapolis Honeywell Regulator Company, Boston, Mass.
Lewis, J. W., Holtzer Cabot Electric Company, Boston, Mass.
Lloyd, R. L., Underwriters' Laboratories Inc., New York, N. Y.
Lounsberry, E. P., Postal Telegraph Cable Company, New York, N. Y.
Loving, R. O., Texas Agricultural and Mechanical College, College Station, Texas.
Luedtke, W. G., Allis-Chalmers Manufacturing Company, West Allis, Wis.
Lukanitsch, L. R., Recording Devices, Inc., New York, N. Y.

Lundberg, M. E. (Member), Uintah Power and Light Company, Roosevelt, Utah.
Malone, J. D., Jr., New Orleans Public Service Inc., New Orleans, La.
Maloney, F. V., Jr., California Edison Company, Los Angeles, Calif.
Marco, G. P., 110 Florence Avenue, Highland Park, Mich.
Margrave, H. E., Kansas Gas and Electric Company, Wichita, Kan.
Marshall, L. E., Jr., Tennessee Valley Authority, Chattanooga, Tenn.
Mason, C. R., General Electric Company, Schenectady, N. Y.
Mason, J. W., 3rd, General Electric Company, Schenectady, N. Y.
Mather, N. W., Otis Elevator Company, San Francisco, Calif.
Matthews, R. B., Illinois Testing Laboratory Inc., Chicago, Ill.
McGuire, W. G., Magnolia Petroleum Company, New Orleans, La.
McBrearty, J. J., Pennsylvania Power and Light Company, Hazelton, Pa.
McConnell, V. O., Sinclair Refining Company, Houston, Texas.
McCrary, D. C., Southwestern Light and Power Company, Lawton, Okla.
McGowan, V. B., Commonwealth Edison Company, Chicago, Ill.
McLeod, L. W., Westinghouse Electric & Manufacturing Company, Wichita, Kan.
McRae, J. W., Bell Telephone Laboratories, Inc., Deal, N. J.
Mechler, E. A., Western Electric Company, Kearny, N. J.
Meister, M. W., Filer and Stowell Company, Milwaukee, Wis.
Mentzer, R. D., Indiana and Michigan Electric Company, South Bend, Ind.
Mezger, G. R., Allen B. DuMont Laboratories, Inc., Upper Montclair, N. J.
Michener, H. P., Jr., Underwriters Laboratories, Inc., New York, N. Y.
Middleton, H. J., Clinton, Ont., Canada.
Miles, H. A., Niagara Lockport and Ontario Power Company, Buffalo, N. Y.
Miller, J. M., Crown Willamette Paper Company, Camas, Wash.
Miller, K. K., Consolidated Edison Company of New York, Inc., New York, N. Y.
Miller, W. E., Bell Telephone Laboratories, Inc., New York, N. Y.
Millman, J., College of City of New York, New York, N. Y.
Mills, J. H., American Lava Corporation, Newark, N. J.
Milner, C. K., Ohio Bell Telephone Company, Cleveland, Ohio.
Mitchell, J. K., Jersey Bell Telephone Company, Newark, N. J.
Moa, H., c/o Mr. C. H. Cho, 71 Hammond Street, Cambridge, Mass.
Moehlenpah, W. G., 818 West Eula Court, Milwaukee, Wis.
Moersch, E. J., General Foods Corporation, Battle Creek, Mich.
Morgan, F. B., Wisconsin Telephone Company, Milwaukee, Wis.
Moreno, A., Jr., General Electric X-Ray Corporation, Chicago, Ill.
Morris, E. R., General Electric Company, Philadelphia, Pa.
Morrison, H. E., 2535 Channing Way, Berkeley, Calif.
Mudie, J. G., Detroit Edison Company, Detroit, Mich.
Mullin, J. T., 20 Blanken Avenue, San Francisco, Calif.
Murray, J. C., Jr., Crescent Instrument Wire and Cable Company, Trenton, N. J.
Nealy, V. L., Texas Pipe Line Company, Houston, Texas.
Neu, J., 16 West 71st Street, New York, N. Y.
Newton, J. P., General Electric Company, Schenectady, N. Y.
Norberg, C. G., United Dry Docks, Inc., Staten Island, N. Y.
Normann, J. A., New York Telephone Company, New York, N. Y.
Noweck, H. E., Western Electric Company, Baltimore, Md.
Oetting, R. L., General Electric Institute, Cleveland, Ohio.
Olson, E. W., Southern California Edison Company Ltd., Los Angeles, Calif.
Ora, S. M., Jr., General Electric Company, Schenectady, N. Y.
Ott, R. V., Carnegie Illinois Steel Company, Youngstown, Ohio.
Owings, S. B., Harnischfeger Corporation, Milwaukee, Wis.
Partridge, W. F., Hart Manufacturing Company, Poughkeepsie, N. Y.
Pearce, T. C. (Member), Potomac Electric Power Company, Washington, D. C.
Pekin, H. T., Tung-Sol Lamp Works, Newark, N. J.
Pendleton, W. W., General Electric Company, Schenectady, N. Y.
Pettersen, R. H., Brooklyn Edison Co., Inc., New York, N. Y.
Peterson, C. R., Washington Water Power Company, Spokane, Wash.
Phillips, A. H., E. M. Gilbert Engineering Corporation, Reading, Pa.
Phillips, T. A., Central Arizona Light and Power Company, Phoenix, Ariz.
Pickell, J., Jr., Southern Bell Telephone and Telegraph Company, Columbia, S. C.
Plumb, L. A., Bausch and Lomb Optical Company, Rochester, N. Y.
Pochkhanawalla, A. M., General Electric Company, Schenectady, N. Y.
Pollack, D., 311 Cooper Street, Camden, N. J.
Ponichtera, A. J., Western Electric Company, Kearny, N. J.
Porter, F. C., 859 South Genois Street, New Orleans, La.
Powell, E. E., Southwestern Bell Telephone Company, Wichita, Kan.
Proffit, A. F., Jr., Federal Power Commission, Washington, D. C.
Qurollo, J. J., Jr., Western United Gas and Electric Company, Aurora, Ill.
Radtke, S. R., 3426 North 1st Street, Milwaukee, Wis.
Radunsky, M. M., Knapp Monarck Electrical Company, St. Louis, Mo.
Ramo, S., General Electric Company, Schenectady, N. Y.
Randall, E. W., Jr., Stone and Webster Engineering Corporation, Erie, Pa.
Rarick, E. A., Albertson Company Inc., Sioux City, Iowa.
Rhyneer, S. M., P. O. Box 121, Absarokee, Mont.
Richman, S. L., Westinghouse Electric & Manufacturing Company, Newark, N. J.
Rigby, C. J., General Electric Company, Schenectady, N. Y.
Rieves, M. H., Commonwealth Edison Company, Chicago, Ill.
Rist, R. M., Gibbs and Hill Inc., New York, N. Y.
Robinson, W. L., Western Electric Company, Chicago, Ill.
Roeseler, W. L., Co. 4729 CCC, Belton, Mont.
Rogo, R. G., Consumers Power Company, Detroit, Mich.
Rohrbaugh, N. B., Paper Mill, Spring Grove, Pa.
Romain, B. P. (Member), Weston Electrical Instrument Corporation, Newark, N. J.
Rosta, J. G., 52 Robinson Street, New Brunswick, N. J.
Roth, E. C., Phillips Petroleum Company, Wichita, Kan.
Sandlin, D. S., Box 395, Ola, Ark.
Sarlin, F., Jr., Chesapeake and Potomac Telephone Company, of Baltimore City, Essex, Md.
Savage, P. R., Woodbury Telephone Company, Woodbury, Conn.
Savoie, C. C., Lula Plantation, Belle Rose, La.
Saxon, F. A., Georgia Power Company, Augusta, Ga.
Scanlan, J. M., Indiana Bell Telephone Company, Indianapolis, Ind.
Schenker, B., Diehl Manufacturing Company, Elizabethport, N. J.
Schjonberg, C. S., 60 East 5th Street, Houghton, Mich.
Schopp, O. J., General Electric Company, Schenectady, N. Y.
Schroeder, T. W., General Electric Company, Schenectady, N. Y.
Schuck, H. V., Trumbull Electric Manufacturing Company, Ludlow, Ky.
Schultis, J. J., Cleveland Railway Company, Cleveland, Ohio.
Schulz, E. H., University of Texas, Austin, Texas.
Schuster, E. F., American Transformer Company, Newark, N. J.
Schwalbert, W. H., Toledo Edison Company, Toledo, Ohio.
Scott, F. T., General Electric Company, Schenectady, N. Y.
Scott, J. M., Jr., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Seaward, C. R., General Electric Company, Schenectady, N. Y.
Seibert, A. P., Apex Steel Company, Los Angeles, Calif.
Shackton, W. H. (Member), Allen Bradley Company, Milwaukee, Wis.
Shanks, W. A., Harnischfeger Corporation, Milwaukee, Wis.
Shapiro, E. J., Standard Air Conditioning Inc., New Rochelle, N. Y.
Sharp, W. O., Bell Telephone Laboratories, Inc., New York, N. Y.
Shipley, R. B., Tennessee Public Service Company, Knoxville, Tenn.
Shirtum, R. C., Emerson Electrical Manufacturing Company, St. Louis, Mo.
Silvey, W. R., New York Telephone Company, New York.
Simpson, H. J., Gearhart Radio Corporation, Fresno, Calif.
Slauson, H. L., Jr., 7 Brookside Park, Old Greenwich, Conn.
Smith, B. H., Jr., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Smith, C. G., Pacific Gas and Electric Company, Salinas, Calif.
Smith, H. A., Youngstown Sheet and Tube Company, Indiana Harbor, Ind.
Smith, H W., Oklahoma Gas and Electric Company, Oklahoma City, Okla.
Smith, C. G., Pacific Gas and Electric Company, Salinas, Calif.
Smith, K. C., New England Power Service Company, Boston, Mass.
Smith, W. P., University of Minnesota, Minneapolis, Minn.
Smithgall, H. E., Jr., Hygrade Sylvania Corporation, Emporium, Pa.
Smrz, G. L., Line Material Company, South Milwaukee, Wis.
Smulin, L. D., Ohio Brass Company, Barberton, Ohio
Soule, J. W., Wisconsin Public Service Corporation, Green Bay, Wis.
Spencer, F. A. (Member), Norwich University, Northfield, Vt.
Sprinkle, R. E., Belmont Radio Corporation, Chicago, Ill.
Stapp, W. H., Jr., Colorado State Highway Department, Denver, Colo.
Stahl, W. H., Jr., Bristol Company, Waterbury, Conn.
Stewart, H. L., Tennessee Valley Authority, Lebanon, Tenn.
Stiles, R. G., P. O. Box 254, Middlebury, Vt.
Stodola, E. K., Radio Engineering Laboratory Inc., Long Island City, N. Y.
Stokely, M. M., J. E. Sirrine and Company, Greenville, S. C.
Stulginskis, B. A. (Member), United Engineers & Constructors, Inc., Philadelphia, Pa.
Stumpf, G. H., Automatic Switch Company, New York, N. Y.
Stutz, G. W., Fairbanks, Morse and Company, Chicago, Ill.
Sudlow, W. H., Georgia Power Company, Augusta, Ga.
Summers, C. M., New York Central Railroad, Chicago, Ill.
Taggart, R. D., Moore Steam Turbine Corporation, Wellsville, N. Y.
Tankersley, C. E., Georgia Power Company, Augusta, Ga.
Tanner, D. W., General Electric Company, Erie, Pa.
Taylor, C. M., 354 Euclid Avenue, Elmira, N. Y.
Taylor, J. K., Rural Electrification Administration, Washington, D. C.
Teitler, A., Jr., Cornell Dubilier Corporation, South Plainfield, N. J.
Terry, J. E., Ritter Dental Manufacturing Company, Rochester, N. Y.
Terwilliger, D. D., Atlantic City Electric Company, Salem, N. J.
Thomas, J. F., Texas Power and Light Company, Dallas, Texas.
Trevino, R. C., P. O. Box 1105, Edinburg, Texas.
Turnau, W. F., General Electric Vapor Lamp Company, Hoboken, N. J.
Ulans, R. I., Consolidated Edison Co. of New York, Inc., New York, N. Y.
Van Haste, W., Bell Telephone Laboratories, Inc., New York, N. Y.
Varhus, H. H., Minneapolis General Electric Company, Minneapolis, Minn.
Volkhardt, V. (Miss), 1101 Emerson Street, Palo Alto, Calif.
Wainola, A. J., 1219 Dwight Way, Berkeley, Calif.
Wainwright, R. M., Montana Power Company, Butte, Mont.
Walker, J. R. (Member), General Cable Corporation, New York, N. Y.
Wallace, F. R., General Electric Company, Tecumseh, Kan.
Walter, G. B., 20 Belmont Street, Englewood, N. J.
Ward, S., Lehigh Foundries Inc., Easton, Pa.
Wareing, J. F., New Bedford Vocational School, New Bedford, Mass.
Warshaw, J., Brush Development Company, Cleveland, Ohio.
Watson, P. R., General Electric Company, Schenectady, N. Y.
Watt, C. W., Jr., Zinsmeyer Company, Los Angeles, Calif.
Weiss, H. M., Brush Development Company, Cleveland Heights, Ohio.
Welch, R. C., General Electric Company, Schenectady, N. Y.
Well, A. C., General Electric Company, Schenectady, N. Y.
Welton, W. R., Connecticut Light and Power Company, Waterbury, Conn.
Weir, A. M., Square D Company, Canada Ltd., Toronto, Ont., Canada.
Wertz, C. W., General Electric Company, Schenectady, N. Y.
Wessells, W. T., Franklin Electric Company, Philadelphia, Pa.
West, S. B., General Electric Company, Pittsfield, Mass.
Westcott, H. H., Ritter Dental Company, Rochester, N. Y.
Westrate, M., Commonwealth and Southern Corporation, Jackson, Mich.
Whitaker, J. A., Douglas Aircraft Company, Ocean Park, Calif.
Whipp, D. M., Box 312, Avalon, Calif.
Whitney, T. G., Electrical Research Products Inc., New York, N. Y.
Wilkens, K. N., Mueller Brass Company, Port Huron, Mich.
Winters, H. R., Oklahoma Gas and Electric Company, Sapulpa, Okla.
Wyndrum, R. W., American Telephone and Telegraph Company, New York, N. Y.
York, J. W., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Zaccaria, J. N., 113 Shaler Avenue, Fairview, N. J.
Zazvorka, J., Jr., 256 Humble Building, Houston, Texas.
Zenoni, W. E., 2750 Paulding Avenue, Bronx, New York, N. Y.

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Foreign

Amado, J. J., Jr., Panama Electrica, S. A., Panama City, Panama.
Carr, T. H. (Member), National Boiler and General Insurance Company Ltd., Manchester, England.
DeMel, C. H. J., Ganges Canal Grid Hydro Electric Scheme, Colombo, Ceylon.

Dexter, L. H., Porto Rico Railway Light and Power Company, San Juan, Porto Rico.
Garcia, J. B., Compania Mexicana de Petroleo "El Aguila," Tampico, Tamps., Mexico.
Gruenberg, W. E., Lago Oil and Transport Company, Ltd., Aruba, Dutch West Indies.
Kapur, R. N., British Insulated Cables Ltd., Peshawar, India.
Kondo, H., Yasukawa Electric Works, Yawata, Fukuoka-ken, Japan.
Moody, H. T. (Member), Rangoon Elec. Tramway & Supply Company, Ltd., Rangoon, Burma.
Stromberg, T. V., ASEA, Vasteras, Sweden.
Tien, C., Lohochai, Yenchenghsien, Honan, China.
Tillekeratne, T. S. V., Ganges Canal Grid Hydro Electric Scheme, Colombo, Ceylon.
Uhl, A. H., Synthetic Carbon and Engineering Company Ltd., Middlesex, England.
Velez, R. J., Central Juneos, Porto Rico.

14 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Eiler, E. E., 101 Brookline Court, Upper Darby, Pa.
Godoy, Ernesto R., Cia. Tel. y Tel. Mex., 16 de Septiembri No. 13, Mexico, D. F., Mex.
Hale, Edward E., Public Service Commission of New York, 80 Centre St., New York, N. Y.
Jones, Harry Kenneth, 5511 Kenmore Ave., Chicago, Ill.
Little, Leroy C., 3414—17th St., N., Cherrydale, Va.
Miyota, Nath S., 916½ Howell St., Seattle, Wash.
Moore, Everett, 821 Sunset Blvd., Los Angeles, Calif.
Peach, Paul S., Upperville, Va.
Pollastro, John B., Helper, Utah.
Sawyer, Fred E., 811 E. Wisconsin Ave., Milwaukee, Wis.
Wickel, F. A., Pier 42, Dollar S. S. Lines, San Francisco, Calif.
Wong, Harry Y. L., 771 Broadway, West New York, N. J.

12 Addressed Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

CONGRÈS INTERNATIONAL des APPLICATIONS ELECTROCALORIFIQUES et ELECTROCHIMIQUES, Schéveningue, June 1936. Recueil des Travaux et Compte-Rendu des Séances. Publié sous la direction de l'institution Néerlandaise des Applications Electrocalorifiques et Electrochimiques, Secrétariat: Arnhem, Nachtegaalspad 1, Pays-Bas. Moorman's Periodieke Pers N.V., La Haye, September, 1936. 336 p., illus., diagrs., charts, tables, 10x6 in., cloth, 6 guilders. Includes papers on industrial electric heating, electric furnaces, and the heat treatment of metals. Some papers are in English, the remainder in French or German.

CONNECTING INDUCTION MOTORS. By A. M. Dudley. 3 ed. N. Y. and Lond., McGraw-Hill Book Company, 1936. 464 p., illustrated, 9x6 in., cloth $3.50. A practical guide to connection and repair of induction motors and in solving questions of making changes to meet varying conditions of voltage, current, and phase.

ELEKTRISCHE MASCHINEN. Volume 4. Die Induktionsmaschinen. By R. Richter. Berlin, Julius Springer, 1936. 440 p., illustrated, 9x6 in., cloth, 30 rm. Discusses the theory and design of single-phase and polyphase generators, motors, and voltage regulators. A-C commutator machines are omitted for consideration in a later volume. Useful to the advanced student.

MACRAE'S BLUE BOOK with which has been incorporated Hendrick's Commercial Register 44 ed. 1936/1937. Chicago, MacRae's Blue Book Company, 3,372 p., 11x8 in., cloth, $15.00 An annual directory following established lines. Includes lists of manufacturers of all industrial products, trade names, and trade facilities. Provides information on the makers of any product.

MATERIALPRÜFUNG mit RÖNTGENSTRAHLEN unter besonderer Berücksichtigung der Röntgenmetallkunde. By R. Glocker. 2 ed. Berlin, Julius Springer, 1936. 386 p., illustrated, 9x6 in., cloth, 33 rm. A practical text on the application of X rays to the study of metals. Discusses the production of X-rays, their properties and application. Emphasis is placed on practical methods of procedure.

MERCURY ARCS. By. F. J. Teago and J. F. Gill. Lond., Methuen and Company, 1936. 104 p., illustrated, 7x4 in., cloth, 3s. A brief outline of the more important electrical, mechanical, and operational features of the mercury arc. Adapted to those who wish a compact statement of modern views.

EIN NEUES ELEKTRISCHES SPRECH GERÄT ZUR NACHBILDUNG der MENSCHLICHEN VOKALE. (Einzelausgabe aus den Abhandlungen der Preussischen Akademie der Wissenschaften Jahrgang 1936. Phys.-Math. Klasse. Nr. 2). By K. W. Wagner. Berlin, Verlag der Akademie der Wissenschaften in Kommission bei Walter de Gruyter & Co., 1936. 44 p., illustrated, 11x6 in., paper, 3 rm. Describes a new electrical instrument for studying and reproducing the vowel sounds of the human voice, and gives the results obtained by the author.

SOUND EQUIPMENT, MOTION PICTURE PROJECTION, PUBLIC ADDRESS SYSTEMS. By J. R. Cameron. Woodmont, Conn., Cameron Publishing Company, 1936. 326 p., illustrated, 8x5 in., cloth, $5.00. Affords a course of instruction in the projection of sound pictures; the construction and operation of equipment is described in detail.

VALUE THEORY and BUSINESS CYCLES. By H. L. McCracken. 2 ed. N. Y. and Lond., McGraw-Hill Book Company, 1936. 259 p., charts, 9x6 in., cloth, $4.00. Designed to bring out the vital and fundamental relationship between value theory and business cycles.

VIBRATION and SOUND. By P. M. Morse. N. Y. and Lond., McGraw-Hill Book Company, 1936. 351 p., 9x6 in., cloth, $4.00. Intended primarily for students of physics and communication engineering, and is based on courses given at the Massachusetts Institute of Technology. Aims to give a general introduction to the theory of vibration and sound.

WIRELESS ENGINEERING. By L. S. Palmer. N. Y. and Lond., Longmans, Green, and Co., 1936. 544 p., illustrated, 9x6 in., cloth, $7.50. A revised and enlarged edition of "Wireless Principles and Practice." Provides information on all branches of radiotelegraphy and radiotelephony, in which theory and practice are combined. Suited to graduate students and practicing engineers in need of a reference book. Contains material on ultrashort-wave radio, beam-antenna systems, propagation through the ionosphere, and quartz oscillators.

APPLIED RADIOCHEMISTRY. (George Fisher Baker Nonresident Lectureship in Chemistry at Cornell University.) By O. Hahn. Ithaca, N. Y., Cornell University Press, 1936. 278 p., illustrated, 9x6 in., cloth, $250. Discusses the utilization of radioactive atoms as representatives of chemical elements in various lines of chemical research. Based upon lectures given at Cornell University in 1933.

SURVEY of the PRESENT ORGANIZATION of STANDARDIZATION; NATIONAL and INTERNATIONAL, published by the Central Office of the World Power Conference, Lond., W.C.2, 36 Kingsway, 1936. 55 p., tables, 11x7 in., paper 3s. 6d. (Gift of American National Committee, Interior Bldg., Washington, D. C.) Presents the facts regarding the national organization of standardization in 33 countries, and of 2 international bodies.

ASTM STANDARDS on ELECTRICAL INSULATING MATERIALS, prepared by Committee *D-9*, Specifications, Methods of Testing. September 1936. Philadelphia, Pa., American Society for Testing Materials, 1936. 329 p., illustrated, 9x6 in., paper, $2.00 ($1.50 to members). Includes the 1936 report of the committee on electric insulating materials with the proposed revisions of standards.

ÉLECTRICITÉ (Agenda Dunod) by L.-D. Fourcault. 56 ed. 392 p. Paris, Dunod, 1937. illustrated, 6x4 in., cloth, 20 frs. Contains numerical and other data frequently wanted by electrical engineers. Small enough for the pocket.

Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a co-operative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Les COMMUNICATIONS RADIO-ÉLECTRIQUES, part 2. By H. de Bellescize. Paris, Gauthier-Villars, 1936. 218 p., illus., 10x7 in., paper, 30 frs. (parts 1 and 2, 50 frs.). Discusses fundamental problems of radio communication, such as the elimination of interference and the increasing of certainty of communication.

ACCOUNTING PRINCIPLES for ENGINEERS. By C. Reitell and C. Van Sickel. 2 ed. N. Y. and Lond., McGraw-Hill Book Company, 1936. 518 p., 9x6 in., cloth, $4.00. Sets forth the elementary principles of accounting upon which accurate cost findings are based, including accounting technique, basic principles of valuation, factory controls, revenue accounts, and the outline of advanced cost finding. Based upon a course given at the University of Pittsburgh.

Book of ASTM STANDARDS issued triennially. 1936. 2 volumes. Philadelphia, Pa., American Society for Testing Materials. Illustrated, 9x6 in., lea., part 1, 898 p., $7.50; part 2, 1477 p., $7.50 (2 parts, $14.) Contains standard specifications, test methods, recommended practices, and definitions formally adopted by the society. One part covers metallic materials; the other, nonmetallic materials.

ATM—Archiv für Technisches Messen. Lieferungen 63–66, September–December 1936. Munich and Berlin, R. Oldenbourg. Illustrated, 12x8 in., paper, 1.50 rm. Devoted to brief accounts of new developments in apparatus and methods for technical measurements.

AMERICAN ELECTRICIANS' HANDBOOK. By T. Croft. 4th edition revised by C. C. Carr. New York and London, McGraw-Hill Book Company, 1936. 1051 pages, illustrated, 7x4 in., leather, $4.00. A handbook for wiremen, contractors, linemen, and plant superintendents.

ANALYSES of BUSINESS CYCLES. By A. B. Adams. New York and London, McGraw-Hill Book Company, 1936. 292 pages, illustrated, 9x6 in., cloth, $3.00. Discusses the causes of business fluctuations and suggests reforms in business practices that would tend to eliminate extreme cycles.

CONNECTING and TESTING DIRECT-CURRENT MACHINES. By F. A. Annett and A. C. Roe. 2nd edition. New York and London, McGraw-Hill Book Company, 1937. 302 pages, illustrated, 9x6 in., cloth, $3.00. Gives practical instructions for the reconnection of d-c machines for a change in voltage or speed, or both, and also for locating and remedying faults.

ELECTRIC ARC WELDING PRACTICE. By H. I. Lewenz. London, Crosby Lockwood and Son, 1936. 126 pages, illustrated, 9x6 in., cloth, 8s. 6d. Describes the principles and practice of arc welding; intended to assist those who have actually to carry out the work.

ELECTRICITY. By W. L. Bragg. New York, Macmillan Company, 1936. 272 pages, illustrated, 9x6 in., cloth, $4.00. Presents the substance of the series of lectures delivered at the Royal Institution in 1934. Deals with the behavior of electrical charges, electrical circuits and magnets, and with such fundamental apparatus as cells and motors. Describes in detail the electrical apparatus in use in everyday life; written for the layman.

ELEKTROMOTOR und ARBEITSMASCHINE. (Schriftenreihe Ingenieurfortbildung, Heft 1.) By F. Moeller and O. Repp. Berlin, J. Springer, 1936. 157 pages, illustrated, 9x6 in., paper, 4.80 rm. A practical textbook on electric motors and their use for driving machinery.

Industrial Notes

Large Motor Standardization.—Electrical drives even for large power requirements have been developed to the extent that they are rapidly becoming standardized. For example, Westinghouse has built thirty-two identical steel mill motors rated at 1250 hp, 600 volts, 300–600 rpm. Installed in 4 different steel manufacturers' plants, each is used for driving cold strip or sheet mills.

New Roebling Branch Manager.—Arthur E. Gaynor has been appointed manager of the New York branch of John A. Roebling's Sons Co., succeeding William P. Bowman, who died on January 22.

Cutler-Hammer Appointment.—T. D. Montgomery was recently appointed by Cutler-Hammer, Inc., Milwaukee, as manager of the foreign sales division.

Emerson Electric Appointment.—The Emerson Electric Mfg. Co., St. Louis, has announced the appointment of Eugene P. Farris as manager of specialty sales, succeeding H. L. Parker, Jr., resigned.

Lincoln Electric Appointments.—The Lincoln Electric Co., Cleveland, Ohio, announces the appointment of B. J. Brugge, who spent 2 years superintending welding operations in the Near East, to the sales staff of its Los Angeles office. W. R. Smith has likewise been appointed to its sales staff. Robert A. Wilson, George Mandula, and A. T. Cox, Jr. have been appointed to the staff of the Chicago office.

Pole Mounted Capacitors.—A new type of weather-proof, steel clad, hermetically sealed 15 kva capacitor unit, suitable for pole mounting on distribution circuits, is announced by Westinghouse Electric & Mfg. Co., East Pittsburgh. These units contain an internal discharge device and are provided with means of mounting on brackets to crossarms or direct to poles, or in groups of four on single angle iron racks, making possible inexpensive installations up to 180 kilovoltamperes on one pair of crossarms.

Marshall Electric Company Sold.—The Ideal Commutator Dresser Co., Sycamore, Ill., announces the acquisition of the Marshall Electric Co. of Elkhart, Ind., manufacturers of automatic regulators for voltage, current and speed control of electrical equipment. The operations of the acquired company will be transferred as rapidly as possible to Sycamore and consolidated with the engineering, research and other departments of the purchaser.

Westinghouse Office to Move.—The Westinghouse Electric & Mfg. Co. will move its Pittsburgh office and some of its general offices now located at East Pittsburgh, to the Union National Bank Building in Pittsburgh about May 1. Occupying nine floors of the building, from the fifth to the thirteenth floors, the Pittsburgh district office, subsidiary district offices and headquarters offices including executive, legal, industrial relations, sales and accounting departments, will be centrally located in the Union Bank Building to facilitate their operations. Formerly the company's district office and subsidiary offices had been in this same building.

Trade Literature

Light-Sensitive Cell.—Bulletin GEA-2467, 16 pp. Describes G-E light-sensitive cell, including complete technical and descriptive data. General Electric Co., Schenectady, N. Y.

Beryllium Copper Alloys.—Folder, 8 pp. Describes the properties of these heat-treatable copper alloys; lists electrical applications, among others, where it may be used to advantage. Beryllium Corp. of Pennsylvania, Reading, Pa.

Transformers.—Bulletin GEA-2442A, 8 pp. Describes unit-type distribution transformers; each unit completely self-contained, incorporating lightning and overload protection, overload indication, etc. General Electric Co., Schenectady, N. Y.

Transformers.—Catalog 105, 16 pp. Describes and illustrates the various phases of distribution transformer manufacture, showing cut-away models and including tables of voltage ratings, accessories, and price lists. R. E. Uptegraff Manufacturing Co., 316 No. Lexington Ave., Pittsburgh, Pa.

Capacitors.—Bulletin GEA-2494, 20 pp. Describes pole type distribution capacitors; a detailed presentation of power factor correction in distribution circuits and the applications and advantages of this type of equipment. General Electric Co., Schenectady, N. Y.

Group Operated Switches.—Bulletin 50, Cat. Sec. No. 1, 4 pp. Describes high-voltage, group operated switches, 88,000-S to 200,000 volts. This type is a rotating insulator, vertical break switch for outdoor substation and transmission line service. Pacific Electric Mfg. Corp., 5815 Third St., San Francisco, Calif.

Outdoor Bus Supports.—Descriptive Data 36-220, 16 pp. Includes specifications for apparatus insulators for standard and heavy duty service, bus supports for various types of mountings, and clamps for outdoor channel buses. Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

Switchboards. Bulletin GEA-2253A, 12 pp., "Modern Switchboard Styling." Largely a photographic treatment of the subject, illustrating the better appearance made possible by semiflush instrument mounting and available with control panels, metal-clad gear, cubicles, etc. General Electric Co., Schenectady, N. Y.

Transformers.—Bulletin 1186, 12 pp. Describes Type "SB" outage free distribution transformers. Discusses principles of operation, how transient surges are diverted, and the methods used to provide protection, as well as construction details of the transformers and protective equipment. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Control Engineering Service.—Booklet, 8 pp. Describes an engineering service for adapting leading manufacturers' apparatus to control problems of all kinds in every industry, and combining consultation, manufacturing, contracting, supervision and guaranteed results wherever a control problem arises to be solved. General Control Co., Cambridge, Mass.

Motor Bearings.—Bulletin EM-7, 40 pp. Describes and illustrates over 200 electric motor bearings. Alphabetical, progressive, and numerical size listings include bearings for any type motor. Sections are incorporated on bronze cored and solid bars, hexagon bars, lead-base and tin-base babbitt and general purpose phosphor bronze bearings. Johnson Bronze Co., New Castle, Pa.

Tachometer. Bulletin 705, 2 pp. Describes a new, normal rate hand tachometer, represented as about the most accurate device made for speed measurements The instrument has a scale graduated into 40 divisions. On the 1000 rpm range, this means that the instrument is arranged for 5 rpm per division and is quite easy to read to one fifth of a division or 1 rpm in 1000. Herman H. Sticht & Co., 27 Park Pl., New York City.

Power-Factor Correction.—Reference table for calculating necessary capacitor kva to correct load to desired power-factor. The chart among other functions computes the reactive kva required to raise the power-factor to any desired percentage. The reverse side of the chart shows the amount of current drawn by capacitors and also specifies the sizes of switches to be used with varying sizes of capacitors. Cornell-Dubilier Corp., South Plainfied, N. J.

Micromax Recorder.—Die-out ND(1), 8 pp. A novel advertising piece demonstrating the Silver-Anniversary Micromax Recorder. Cut to the actual shape of the recorder, the door of the case opens and swings out the chart carriage and whole mechanism into view, just as may be done with the actual instrument. Inside and out each unit is in true perspective, with chart and record in color. Though its range is that of a typical temperature recorder, the model demonstrates equally well the automatic indicating and recording of any of a wide variety of process conditions—not only temperature, but chemical concentration, pH, per cent CO_2, smoke density, liquid level, speed, frequency, load, voltage, etc. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.